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BRITISH LOCOMOTIVES IN 1926

DESIGNS AND WORK,

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Figs. 1 to 5, pp. 178 and 179.

I. — Designs.

Had it not been for the General Strike of railway and transport workers, which, from May 4 to 14, brought transport almost to a standstill, and the mining dispute which continued until the end of November, there is every reason for thinking that the year 1926 would have been appreciably better than its predecessor in regard to industry and trade, and that the railway companies would have benefited correspondingly. There were, indeed, indications that the year would have seen considerable improvements in railway traffics, and that it would have had to its credit many notable new locomotive designs, besides important train service developments. Instead, the railway companies have been placed in an unprecedentedly difficult position, train service developments of note could not even be considered, and the record of more or less novel locomotive designs associated with 1926 is a very meagre one. There are, however, at least two designs belonging to 1926 which rank as notable, and three others which possess sufficient interest for detailed reference here.

In last year's article (1) mention was made of a 2-6-6-2 *Garratt* locomotive design, under construction by Beyer, Peacock & Co., Ltd., for the London Midland & Scottish Railway. Particulars were, indeed, given, with leading dimensions;

(1) See *Bulletin of the Railway Congress*, February 1926 number, p. 73.

but, so far, the engine itself has not been completed, due to the peculiar problems of the year, and it is not expected to be placed in service until some time in 1927. Reference was also included to a 2-6-0 design put in hand by Mr. George Hughes for mixed-traffic service on the London Midland & Scottish Railway. No. 13000 (fig. 1, *a*), the first of the class, was placed in traffic in the summer by Sir Henry Fowler, K. B. E., now Chief Mechanical Engineer of that line. The type is a new one for the London Midland & Scottish system though traffic on several sections is very suitable for such an engine. As the design includes a number of features of interest, it may be described more or less in detail. The engine has been designed to handle fast goods traffic and heavy excursion trains. Steam distribution is by piston valves above the cylinders, operated by Walschaerts valve gear. Wakefield mechanical lubricators are fitted on each side of the engine on the platform, one side for axleboxes, the other side for cylinders and piston valves. The cab is large and roomy, and is fitted with side and front windows, giving a good lookout for the enginemen. The pony truck is of the swing link type, and has a side play of 3 1/4 inches each way. The springs for the coupled wheels and pony truck are of the laminated type. The six-wheeled tender, which carries 3 500 gallons of water and five tons of coal, is of the self-trimming type, and is fitted with water pick-up apparatus.

Otherwise, there is not much new to record in regard to the London Midland & Scottish Railway. Further Midland type 4-4-0 three-cylinder compounds have been placed in service, also additional 0-6-0 superheater goods engines and a number of 0-6-0 side tank engines. A 4-6-0 engine of the « Claughton » class was fitted with Caprotti valve gear, and a fair amount of rebuilding and re-boilering was carried out, but nothing of an outstanding character. A Ljungström turbo-locomotive, built by Beyer, Peacock & Co., Ltd., was tested on the London Midland & Scottish Railway, as a matter of arrangement between the builders and the railway company, but no results have been made public.

On the London & North Eastern Railway, further 0-6-2 superheater tank engines of the class mentioned in last year's article have been constructed, while two classes of 0-6-0 tender locomotives have been placed in service, built at Darlington. They are generally similar, except that one class, intended for general goods traffic and occasionally heavy passenger service, has 5 ft. 2 in. coupled wheels; the other, designed for mineral traffic where eight-coupled engines cannot be used or are not required, has 4 ft. 8 in. coupled wheels. One of the former is illustrated in figure 2, *b*. Inside cylinders are employed with piston valve steam chests above them, the middle pair of coupled wheels being the drivers. The cylinders are cast in one with the steam chests and mounted between the frames in a slightly inclined position. These details, as well as the valve motion, which latter is of the Stephenson link pattern and gives a long valve travel, conform to modern London & North Eastern Railway standards, as also does the boiler and its equipment. The boiler is set with its centre line 8 ft. 9 1/2 in. above rail level, and the total overall height of the engine is 13 feet, a dimension which permits of the new class being used on any section of the London & North Eastern Railway. A commodious type of cab is provided.

A three-cylinder 4-4-0 design is in course of preparation, but has not appeared at the time of writing. Otherwise, there is little to record of a special character on this line.

The Great Western Railway has provided even less material of interest in this connection. An enlarged version of the well-known « Castle » class engines is anticipated, designed for a steam pressure of 250 lb. per square inch, but further particulars are not yet available. Some of the new « Castle » class engines built during the year have tenders of a new design. These are larger and of higher capacity than the previous tenders, which latter had a portion of the tank carried between the frames below the footplate level, whereas in the new design the whole of the tank is above the footplate, which accounts for the greater height from rail level. A tank of this description is much more simple to construct and maintain, and permits of a greatly improved design of underframe being used. The plates forming the coal space are sloped towards the centre and front of the tender, with the result that the coal is automatically fed on to the shovel plate, thus making the tender self-trimming and avoiding the necessity of the fireman raking the coal forward. The water capacity of the new tender is 4 000 gallons and the coal capacity six tons. Some small 0-4-0 tank engines for dock service may also be mentioned.

On the Southern Railway, however, no fewer than three locomotive designs call for attention, though last year mention was made of two of them : 1), a three-cylinder 2-6-4 express tank engine No. 890A, *River Frome* (fig. 3, *c)*, and (2) a 4-4-0 class (fig. 4, *d*).

The 2-6-4 tank engine is a development of a two-cylinder class introduced first in 1917 (one engine only) and multiplied in 1924. It is a companion instance of the trial fitting of three cylinders to a two-cylinder design to that carried out in 1923, when Mr. Maunsell brought out a three-cylinder version of his well-known 2-6-0 mixed-traffic engines.

The cylinders and motion of No. 890A are interchangeable with the 2-6-0 three-cylinder engine No. 822, whilst the boiler, wheels, and other details are identical with those of the two-cylinder tank engines. The arrangement of valve gear, as before, consists of two Walschaerts gears for the valves of the outside cylinders, while rocking levers, connected to these gears, operate the valve of the inside cylinder through extension rods. The single throw crank axle is of the built-up type with extended webs to form counterweights. These balance the crank pin and part of the connecting rod, so that the same wheel centre castings as used for the two-cylinder engines can be utilised by a little adjustment to the balance weights. The inside connecting rod is of the strap bolt pattern, while the outside rods are of the plain bushed type. The engine has, as far as possible, been made identical with the two-cylinder engines of the « River » class at present working on the Southern Railway, with the object of comparing three and two-cylinder simple engines, both as regards performance and cost of maintenance in passenger service.

Fifteen of the new 4-4-0 engines were built by the North British Locomotive Co., Ltd., Glasgow, for the Eastern Section of the Southern Railway. In general design the engines are duplicate with the « L » class introduced in 1914, but improvements have been made by Mr. R. E. L. Maunsell in various details. The boiler pressure has been increased

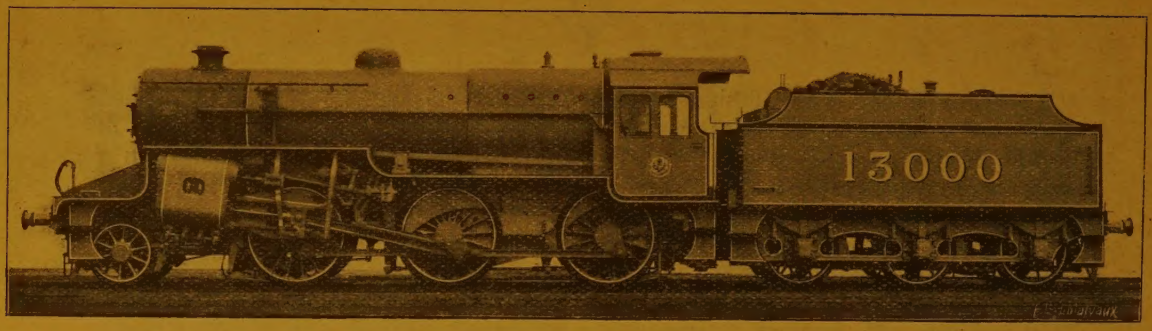


Fig 1. — 2-6-0 mixed traffic locomotive, London Midland & Scottish Railway.

Sir Henry Fowler, K. B. E., Chief Mechanical Engineer.

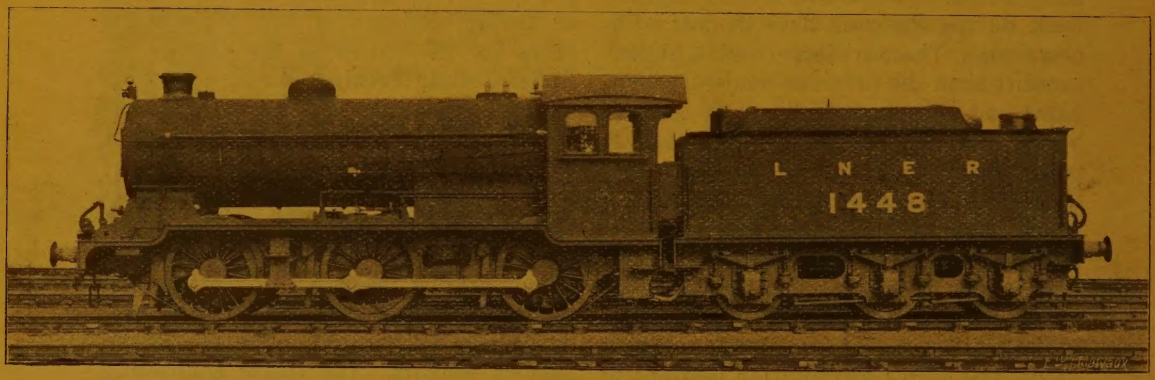


Fig. 2. — 0-6-0 superheater goods locomotive, London & North Eastern Railway.

Mr. H. N. Gresley, C. B. E., Chief Mechanical Engineer.

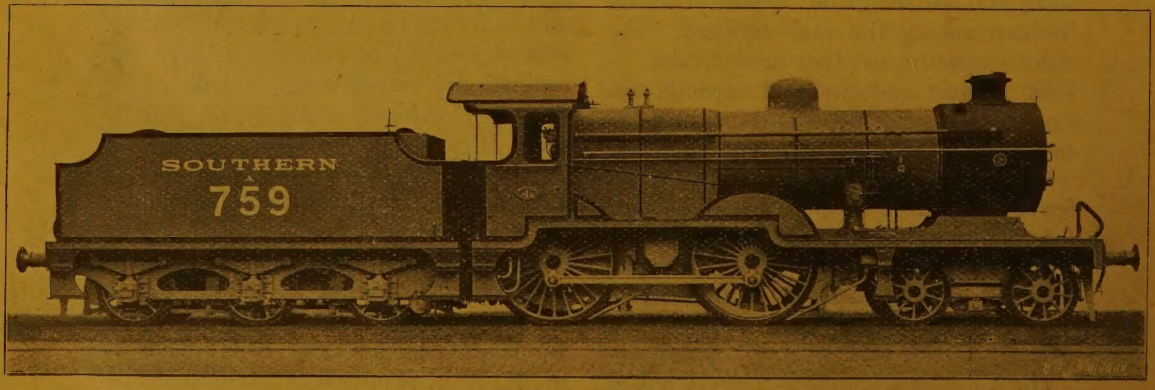


Fig. 4. — 4-4-0 main line locomotive, Southern Railway.

Mr. R. E. L. Maunsell, C. B. E., Chief Mechanical Engineer.

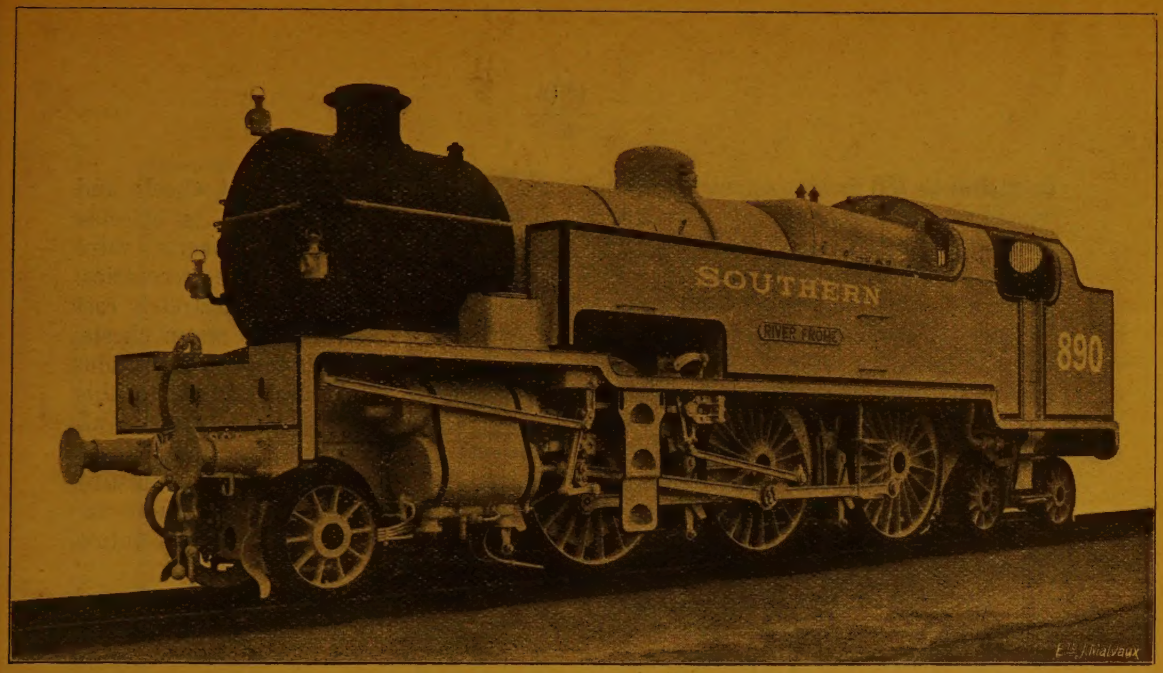


Fig. 3. — Three-cylinder 2-6-4 main line tank engine, Southern Railway.

Mr. R. E. L. Maunsell, C. B. E., Chief Mechanical Engineer.

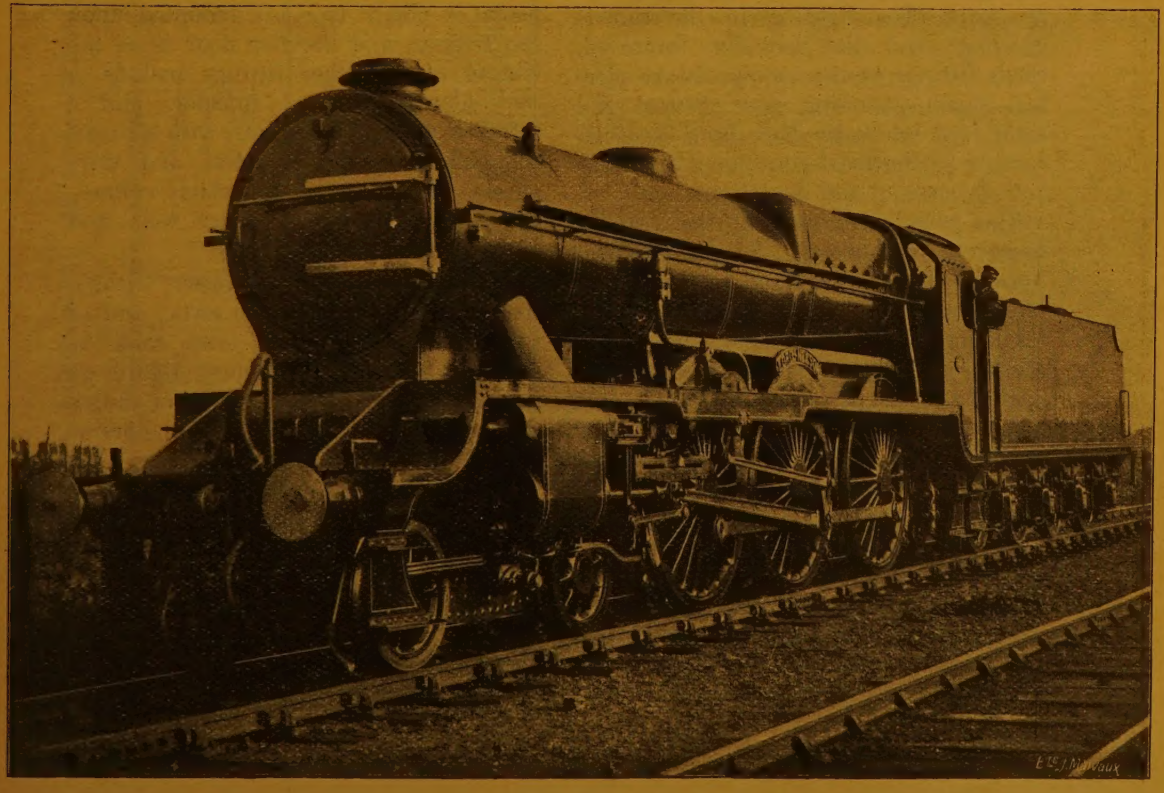


Fig 5. — Four-cylinder 4-6-0 locomotive, Southern Railway.

Mr. R. E. L. Maunsell, C. B. E., Chief Mechanical Engineer.

from 160 to 180 lb. per square inch, and the cylinder diameter reduced from 20 1/2 to 19 1/2 inches, so that the tractive effort is not appreciably affected. The Stephenson link motion has been entirely re-modelled and the valve travel increased to 5 3/8 inches in full gear, the lap being increased from 7/8 to 1 3/16 inches.

The engines have the « Maunsell » type superheater header with snifting valves and a hydrostatic sight feed lubricator having separate condenser for cylinders and valves. The smokebox arrangement has been re-designed and a standard chimney fitted. The flat-sided tender with enhanced brake power is also duplicate with the 2-6-0 type engines of Mr. Maunsell's design. The cab roof has been extended backwards, side windows provided and the large tool boxes behind the splashers have been replaced by tip-up seats. The lighting in the cab is excellent and the look-out improved. Such fittings as the vacuum brake ejector, steam reversing gear control and sight feed lubricator have been carefully located in the most convenient positions for observation and operation.

The principal design of the year is, however, undoubtedly No. 850E, *Lord Nelson* (fig. 5, *e*), placed in service by Mr. Maunsell in October. In point of tractive power development, the engine marks an advance upon the « King Arthur » class described last year, and, on this basis ranks as the most powerful 4-6-0 type engine in Great Britain, the tractive effort, at 85 % of the boiler pressure, 220 lb. per square inch, being 14.95 tons (33 500 lb.).

The inside cylinders are placed slightly in advance of the outside ones and are formed in one casting with their piston valve steam chests above them. These cylinders drive the crank axle of the foremost pair of coupled wheels, and steam distribution to them is effected by separate inside Walschaerts valve motions actuated by single eccentrics. The outside cylinders are separately cast together with piston valve steam chests, and these drive the middle pair of coupled wheels, steam distribution in this case being performed by outside Walschaerts gearing having the usual arrangement of return cranks. An interesting feature of the design is that there are eight separate impulses per revolution of the coupled wheels.

The boiler is of large proportions, and a new feature is a Belpaire pattern firebox, of liberal dimensions, with sloping roof and backplate. The tubes are of moderate length. The superheater header is of the « Maunsell » type, with air relief valves. Safety valves of the Ross patent « pop » type are mounted upon the firebox, and the fire door is of the sliding type. Other fittings include a soot blower, exhaust injector, and a 4-feed sight feed lubricator, with separate condenser for the cylinders and valve chests. The cab is particularly commodious, and the controls are well and conveniently arranged.

The engine in working order, without tender, weighs 83 tons 10 cwts., and of this approximately 62 tons rank as adhesion weight, the highest figure yet reached in Great Britain both for individual axle loading and collective adhesion weight in a 4-6-0 type of engine. The tender is of the 8-wheeled double-bogie pattern, and has a capacity for 5 000 gallons of water and five tons of coal. Three steel barrels mounted abreast at the rear end of the tender serve the purpose of reservoirs for increasing the power of the vacuum brake actuating the blocks on the tender wheels.

LEADING DIMENSIONS OF LOCOMOTIVES ILLUSTRATED AND DESCRIBED.

T = Tank engine.

Reference.	Figure.	RAILWAY.	Type.	Cylinders. Diameter and stroke (inches).	Diameter of coupled wheels.	Heating surface (square feet).			Grate area (square feet).	Steam pressure (lb. per square inch).	Weight (engine only) in working order (tons).
						Tubes.	Fire box.	Super-heater.			
(a)	1	London Midland & Scottish. . .	2-6-0	21 × 26	5 ft. 6 in.	1361	160	307	27.5	180	66
(b)	2	London & North Eastern. . . .	0-6-0	20 × 26	5 ft. 2 in.	—	—	—	26	180	57.8
(c)	3	Southern	2-6-4 T	16 × 28 (3)	6 feet.	1390.6	135	285	25	200	58.7
(d)	4	—	4-4-0	19 1/2 × 26	6 ft. 8 in.	1252.5	154.5	235	22.5	180	58.5
(e)	5	—	4-6-0	16 1/2 × 26 (4)	6 ft. 7 in.	1795	194	376	33	220	83.5

The engine has been constructed to haul trains of 500 tons at an average speed of 55 miles per hour, the heaviest trains on the Southern Railway at the present time being from 425 to 450 tons. The overall dimensions of the engine are such as to enable it to run on any main line of the Southern system.

There was, of course, a fair amount of rebuilding and re-boilering during 1926 on all lines, and a few additions to standard designs, but beyond what has been mentioned there is nothing calling for attention. In view of the coal strike a number of London Midland & Scottish engines were adapted to burn oil and this was done quite successfully. A number of London & North Eastern engines were also altered for oil fuel.

II. — **Work**.

So far as train service developments are concerned, 1926 was necessarily a « dead » year, and the only item of particular interest which the writer can call to mind is the alteration of the Leeds and Bradford Pullman Car express of the London & North Eastern Railway to call at Wakefield to allow of the running of through coaches to and from Halifax. The down train, at 11.20 a. m., makes its long non-stop run from King's Cross (London) as far as Wakefield only, 175 3/4 miles, in 188 minutes, instead of to Leeds (185 3/4 miles). The up train is allowed 1 minute longer from Wakefield to London. It may be mentioned, too, that commencing January 1, 1927, the London & North Eastern Railway introduced a Pullman and Restaurant Car boat express from Liverpool Street (London) at 10.0 a. m. to Harwich (Parkeston Quay) in the same hard time as the night boat train, 85 minutes. The up train is allowed a little longer.

During the general strike, train services were, inevitably, entirely disorganised, while the necessity for conserving coal stocks, even when foreign coal was utilised, caused certain companies to reduce their services considerably during the long-continued coal strike. It is, however, worthy of special remark that, for the summer holiday period, all companies maintained nearly, if not quite, full summer facilities, a course which was distinctly praiseworthy, and which enabled the holiday traffic to be operated without undue inconvenience to passengers and thus reduced the losses on the passenger side, though, necessarily, at considerable expense.

In view of the special interest attaching to the new Southern Railway locomotive *Lord Nelson* (fig. 5), a fairly full account of a special inaugural trip may be given, though here the writer, who was unable to travel, much to his regret, must refer to Mr. Cecil J. Allen's account contributed to *The Railway Magazine*. The train was the « Atlantic Coast » express, loaded to 420 tons. Nothing special was attempted on the down journey, though time was slightly improved upon. Woking, 24.4 miles, was passed in 29 minutes, and Basingstoke, 23.5 miles further, 24.8 minutes later. The next 18.5 miles to Andover took 18.3 minutes, speed here being about 83 miles per hour, and the final 17.4 miles to Salibury were covered in 17.3 minutes. In the course of the journey 75.4 miles were run in 75 minutes.

Returning, with 415 tons, a late start afforded opportunity for special work. From Salisbury to passing Andover (17.4 miles) took 24.8 minutes (a hard stage), and the next 18.5 miles to Basingstoke occupied 17.5 minutes. Thence to passing Clapham Junction (reduced speed) the 44 miles were run in barely 37 minutes, the average speed for 36 miles being 73.9 miles per hour. Incidentally, 68.9 miles were run in 60 minutes, while the total distance of 83.8 miles from Salisbury to Waterloo was covered in 85.5 minutes, against 92 scheduled.

On the same down train, but with an ordinary load, a « King Arthur » class 4-4-0 No. 773E, *Sir Lavaine*, had a load of about 330 tons. From Waterloo, Surbiton (12.1 miles) was passed in 16.6 minutes, Woking (24.4 miles) in 28.5 minutes, and Basingstoke (47.9 miles) in 53.3 minutes, whistling several times suggesting that adverse signals were sighted here and there and that undue speed might involve a stop. Thence to Andover Junction, 18.5 miles, were run in 18.1 minutes, and the final 17.4 miles to a stop outside Salisbury occupied 17 minutes.

A similar engine, No. 449, *Sir Torre*, over the main line difficult grades beyond Salisbury, passed Templecombe (28.2 miles) in 34.1 minutes, and passed the summit of Colinton bank (41.8 miles further on) 45.7 minutes later, notwithstanding banks of 1 in 80 and several miles of about 1 in 70. The final run down to Exeter, 18 miles, took 19 minutes.

Returning, a similar engine, with 330 tons, passed the summit of Honiton bank, 18 miles, in 25.6 minutes, and then ran to a stop at Yeovil Junction, 31.3 miles in 33.7 minutes. The 10.5 miles thence to Templecombe, start to stop, took 20 minutes, and the final 28.2 miles to Salisbury, 35 minutes. An old 4-4-0, No. 282, but rebuilt and superheated, then took charge, and passed Andover Junction, 17.4 miles, a hard stage, in 24.1 minutes, covered the next 18.5 miles

to passing Basingstoke in 20.1 minutes, and completed the remaining 46.5 miles, to a stop beyond Vauxhall in 50 minutes, including slight delays.

On one of the Continental expresses between Victoria (London) and Dover, one of the « King Arthur » 4-6-0's, No. 771, *Sir Sagramore*, had a load of 430 tons. It was banked out of the terminus, as usual, but as the route taken is very complicated, it will be best to analyse the running from passing Orpington, to which point checks and speed reductions are frequent. From that station, passed at 45 miles per hour, the hard 8.2 miles to Sevenoaks took 11.7 minutes, and the next 7.5 miles to the usual slack for Tonbridge Junction, 8.3 minutes. The rest of the route is fairly straightforward, though not altogether easy. The fast stretch of 26.6 miles to passing Ashford at speed occupied 25.7 minutes, and the next 9.3 miles to Sandling Junction, 9.9 minutes. The concluding 6.3 miles to a momentary signal stop near Dover were completed in 9.6 minutes.

One of the late Brighton 4-6-4 express tank engines, No. 329, with the « Southern Belle » Pullman train, loaded to 360 tons, passed East Croydon (10.5 miles) in 17 minutes (a good time for this stage), and passed Earlswood, 11.4 miles, in 15.1 minutes. The next stage, to passing Haywards Heath, 16.1 miles, with one check, occupied 17.7 minutes, and the remaining 12.9 miles to Brighton, 15.6 minutes, a loss of time, but accounted for by delays *en route*. A less important train, worked by one of the « King Arthur » 4-6-0's, newly introduced on this route, made a rather interesting run. No. 798E, *Sir Hectimere*, had about 200 tons. The 12.9 miles from Brighton to Haywards Heath, start to stop, took 19 minutes, the greater part involving climbing. Thence to East Croydon, again start to stop, the 27.5 miles occupied 37.8 minutes, including two checks.

On the London Midland & Scottish Railway special interest still attaches to the work of the 4-4-0 three-cylinder compound locomotives of Midland design, though the considerable number now in service, on the London & North Western, Caledonian and Glasgow & South Western sections, renders their appearance elsewhere than on Midland Division duties much less notable than was the case a year or two ago. Further, while they do a great deal of very heavy work singlehanded, many of the hardest turns necessarily involve double-heading. Thus, No. 1096 was assisted by an L. N. W. 4-4-0 on the 10.30 a. m. Liverpool and Manchester express from Euston, the load being 450 tons, including passengers and luggage. Banked from Euston to Chalk Farm, the initial climb proved, of course, an easy task, but two relaying slacks were included in the 31.7 miles to Tring summit, passed in 40.6 minutes, while a series of checks and two stops at Wolverton and Castlethorpe, due to a signal block circuit failure, caused the 62.8 miles to Blisworth to take 81.9 minutes. Thence the 19.8 miles to passing Rugby took 21.9 minutes, the 51 miles to Stafford 52.6 minutes, and the remaining 24.5 miles to Crewe (the first booked stop), 28.6 minutes. Even with delays, however, the time for the 158 miles was only 183.8 minutes, 8 minutes over schedule time, though a good 12 minutes had been lost.

In the opposite direction, an oil-burning four-cylinder 4-6-0 of the « Claughton » class, No. 1345, *James Bishop*, with 320 tons, ran from Crewe to Stafford, start to stop, very easily in 31.3 minutes; and (booked non-stop to London from

Stafford) passed Rugby (51 miles) in 56.6 minutes; Bletchley (35.9 miles) in 37.5 minutes; and completed the 46.7 miles to Euston in 50.6 minutes.

North of Crewe, principal interest attaches to the Preston-Carlisle section. A Lancashire & Yorkshire type four-cylinder 4-6-0, No. 10463, with 270 tons, was delayed by permanent way works two or three times before stopping at Tebay for banking assistance, the 53.3 miles from Preston taking 71.9 minutes. With a banker, Shap summit was passed in 11.1 minutes (5.6 miles, 4 at 1 in 75), and the final 31.3 miles to Carlisle took 31.6 minutes. In the opposite direction, a two-cylinder 4-6-0 No. 5774, burning oil, was assisted to Shap summit by a 2-4-0 about 40 years old, No. 883, *Phantom*, with a load of 330 tons. The hard 31.3 miles to a stop to detach the pilot occupied 43.7 minutes. Thence No. 5774, with two or three permanent way slacks, passed Preston (58.7 miles) in 66.4 minutes and covered the 26.9 miles thence to Warrington (passing time) in 33 minutes. Onwards to Crewe, however, signal checks spoilt the run.

In Scotland a Caledonian 4-4-0, No. 14463, with 290 tons, and once badly checked, ran from Carlisle to Lockerbie, start to stop, 25.8 miles, in 36.4 minutes; and then covered the stage of 13.9 miles to Beattock in 18.5 minutes. A similar engine, No. 14499, with 300 tons, climbed with a banker to Beattock summit in 21 minutes (10 miles mainly at 1 in 75), and then ran the 23.8 miles to Carstairs in 26.6 minutes. The remainder of the journey to Stirling is too complicated to permit of continued high-speed running. In the opposite direction, another Caledonian 4-4-0, No. 14462, with 280 tons, was in difficulties owing to bad fuel (during the coal strike) as far as Carstairs, but, after stopping there for attention, climbed to Beattock summit (23.3 miles) in 36.1 minutes, and stopped at Beattock station (10 miles) 11.5 minutes later. Thence to Lockerbie (13.9 miles) took 16.4 minutes, and the final 25.8 miles to Carlisle, 32.1 minutes, in each case start to stop.

On the Midland section of the London Midland & Scottish Railway a compound 4-4-0, No. 1030, burning oil, gave an interesting run from Leicester to London, with a load of 220 tons, the complete journey of 99.1 miles being covered in 108.2 minutes, a signal stop being only avoided by lengthy very slow running, there being also one permanent way check and two speed orders. From Leicester to passing Kettering the 27.1 miles occupied 32 minutes; thence to Bedford, 22.2 miles, took only 20.2 minutes; and the 19.6 miles to Luton, including the long check mentioned, occupied 25.5 minutes. The final 30.2 miles to St. Pancras were completed in 30.7 minutes.

On the East Coast route a three-cylinder 4-6-2, No. 2548, *Galtee More*, had a load of 450 tons to work to Grantham unaided. The hard 12.7 miles from King's Cross to passing Potters Bar took 20.7 minutes, and, with one bad permanent slack, Hitchin, 19.2 miles, was passed 22.5 minutes later. Near Three Counties, the next station, a quick stop was made for engine examination, but after standing 5 minutes the journey was continued, the 40.7 miles from passing Three Counties station to passing Peterborough slowly taking 41.2 minutes. Thence the climb to Stoke Summit (23.7 miles) took 26.9 minutes, and Grantham was reached in a further 6.4 minutes (5.4 miles), making the total time, including the stop near Three Counties, 126.5 minutes for 105.5 miles. A similar

engine, No. 2555, *Centenary*, passed Doncaster (50.5 miles) in 54.9 minutes from the Grantham start, and, with several delays, completed the 32.2 miles to York in 44.6 minutes.

In the opposite direction, a corresponding load, 440 tons, was worked by two 4-4-2 locomotives, Nos. 4401 and 3291. These covered the 32.2 miles to Doncaster in 38.9 minutes from York. There the load was reduced to 420 tons, and the same two engines covered the 55.9 miles to Stoke summit in 62.5 minutes, completing the 23.7 miles to a stop at Peterborough in the fast time of 22.5 minutes. There, 4-4-2 No. 4443, and 4-4-0 No. 3045, took charge, but were handicapped by necessary transfers from fast to slow lines and back near Abbotts Ripton, so that the 17.5 miles to passing Huntingdon took 26.4 minutes. Thence to Potters Bar summit (46.2 miles) took 47.9 minutes, after which another delay caused the remaining 12.7 miles to King's Cross to take 20.4 minutes.

Between York and Newcastle the down journey produced little of interest, but a North Eastern type 4-6-2 engine, No. 2402, *City of York*, with 420 tons from Newcastle, passed Darlington, 36-5 miles, in 47.9 minutes (this is not a high-speed section), and then ran to York, 44.1 miles, very easily in 54 minutes.

On the Newcastle-Edinburgh section, Gresley 4-6-2 No. 2582, *Sir Hugo*, with 460 tons, passed Morpeth (16.5 miles) in 25 minutes from Newcastle, with one bridge-repairing slack, Alnmouth (18.3 miles) 20.9 minutes later, and reached Berwick (32.2 miles further) in another 31 minutes, thus completing the 67 miles from Newcastle in 76.9 minutes, with a big load, in bad weather, and over a hard route. Continuing, the summit at Penmanshiel Tunnel was passed in 28 minutes (17.5 miles), a very hard climb, and the remaining 40 miles to Edinburgh (Waverley) were run in 44 minutes. Returning, with 420 tons, a similar engine, No. 2565, *Merry Hampton*, covered the 29 miles to Dunbar, start to stop, in 38.4 minutes. Thence the 11 miles to Penmanshiel Tunnel took 18.4 minutes and the following passing times were then achieved : Berwick (17.5 miles), 20.4 minutes; Alnmouth (32.2 miles), 35.9 minutes; Morpeth (18.3 miles), 19.9 minutes; and Newcastle, a further 16.5 miles, was reached 23.1 minutes later.

Finally, two journeys may be described between London and Plymouth, by Great Western Railway, the return being in a special through boat train for trans-Atlantic passengers, which gave some notable running. The down train consisted of 8 large vehicles to go through (255 tons), two to be slipped at Exeter (70 tons), two to be slipped at Taunton (64 tons), and two to be slipped at Westbury (70 tons), making the total load 459 tons empty, or about 490 tons loaded. The engine was No. 4073, *Caerphilly Castle*, the first of the now famous class. Running was at first somewhat sluggish, and 40.9 minutes were taken to pass Reading (36 miles). Thence to Newbury the 17.1 miles took 22.9 minutes this section being mainly hard, and the next 17 miles to Savernake summit occupied 20.6 minutes. A fast run down followed to the Westbury slack (70 tons slipped), the 25.5 miles being run in 22.6 minutes. Thence to another slack at Frome the 5.9 miles took 8 minutes. Then followed a fast run to Taunton, 41.6 miles in 43 minutes. Here, a further two vehicles were slipped, so that the load had become about 340 tons for the steep climb to Whiteball tunnel. This stretch of 10.9 miles took 12.8 minutes, and a fast

run down to Exeter (19.9 miles) was made in 19.6 minutes. There two further vehicles were slipped, and with 270 tons No. 4073 passed Newton Abbot (20.2 miles) 23.2 minutes later, before tackling the terrific gradients of the section thence to Plymouth. Here there are grades of 1 in 37, 42, 51, etc., but, notwithstanding the difficulties, the 31.8 miles to the first stop, at North Road, Plymouth, were completed in 44.3 minutes, and, despite the poor start, the complete run of 225.7 miles from London was made in only 45 seconds over the 247 minutes allowed.

The return journey was, however, the great feature, made in a special train run for a party of American hotel people who had arrived that day at Plymouth from the United States. The first special train represented a load of 280 tons, and was worked by No. 4083, *Abbotsbury Castle*. Starting from the Docks station at Plymouth, the special passed North Road station four minutes later, and covered the very hard stage thence to Newton Abbot (31.8 miles) in 38.2 minutes. Thence to Exeter the 20.2 miles took 23 minutes, while the climb to Whiteball summit was made in 20.6 minutes (20 miles), practically the mile-a-minute rate, notwithstanding adverse gradients. The 10.8 miles down to Taunton took 9 minutes, and the next 41.6 miles to the Frome slack, 41.5 minutes. The next 5.7 miles to the Westbury slack took 6.8 minutes. From there to the summit near Bedwyn (29 miles) occupied 28 minutes, and the next 13.3 miles to Newbury, 11 minutes. Reading, 17.1 miles, was passed 15.6 minutes later, and the final run of 36 miles to Paddington took 35.4 minutes. The complete run of 226.9 miles was thus made in 235 minutes. A second train, slightly heavier, drawn by No. 4085, *Berkeley Castle*, took almost exactly the same time, but with slight intermediate differences.

A comparative study of different methods of propulsion, [1]

By F. CORINI,
PROFESSOR OF ENGINEERING, DEPUTY TO THE ITALIAN PARLIAMENT.

Figs. 1 and 2, p. 187 and 189.

1. *Introduction.* — In land transport, the propulsion of self-propelled vehicles is assured by the « driving wheels » which, owing to their adhesion, are able to propel the vehicle.

For transport on the water and in the air, the propulsion is generally obtained by the use of screws or « propellers ».

It is interesting to examine the characteristics of these two types of propulsion, and, by comparing them, to arrive at conclusions which would facilitate their use in new and unexpected ways.

In this field, as in others in science and industry, new applications of these methods have been made tentatively before the problem has been systematically studied. Aerial railways with carrier cables and motor coaches fitted with propellers as a means of propulsion have been built [2]. Without claiming that this is the only practical application of the principles which we are about to discuss, nor stating that other and more interesting applications will not be discovered in the course of time, we will content ourselves with saying that the initiative which has been shown is such as to justify a lively interest in the scientific and technical problem which we propose to study.

2. *Driving wheels.* — Consider a locomotive driving axle connected by a connecting rod and crank to the piston [3].

If we call p the mean pressure in cylinder I (fig. 1) and S the area of the piston,

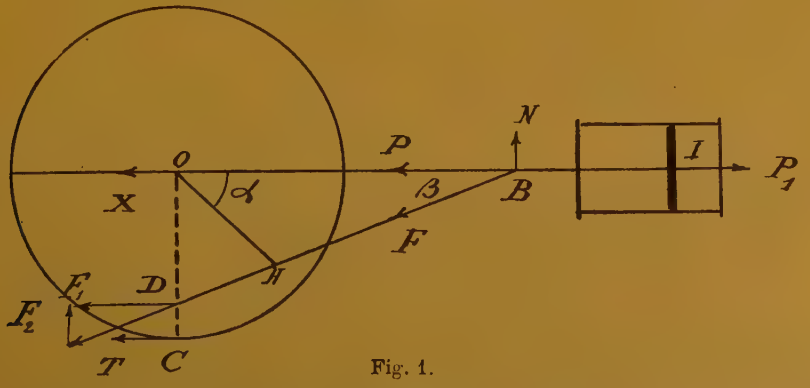


Fig. 1.

(1) This article is also appearing in the Italian publication : *Il Monitore tecnico.*

(2) *Revue générale des chemins de fer*, 1926.

(3) CORINI : *Lezioni di Ferrovie.*

the steam transmits to the frame of the locomotive the force $P = p \cdot S$ in the direction P_1 and the same force on the piston in the direction P. The force applied to the crosshead and slide bars is split up into two : the first N, perpendicular to the slide bars, is transmitted to the frame; the other, F, operating in the direction of the connecting rod, is transmitted to the wheel through the crank and in the direction previously stated.

With the notations in figure 1, it follows :

$$(1) \qquad \begin{cases} N = P \tan \beta. \\ F = \dfrac{P}{\cos \beta}, \end{cases}$$

The force F meets at D the vertical from O; at that point it can be resolved into two : the first, F_1, parallel to OB, and the other, F_2, vertical; which gives :

$$(2) \qquad \begin{cases} F_1 = F \cos \beta = P. \\ F_2 = F \sin \beta = P \tan \beta = N. \end{cases}$$

We are able to resolve F_1 into two parallel forces : one, X, applied at O, the other, T, at C. If R is the radius of the wheel, we have :

$$(3) \qquad \begin{cases} X = F_1 \cdot \dfrac{R - OD}{R}; \\ T = F_1 \cdot \dfrac{OD}{R}; \end{cases}$$

and consequently :

$$(4) \qquad \begin{cases} X = P\left(1 - \dfrac{OD}{R}\right); \\ T = P \dfrac{OD}{R}. \end{cases}$$

The propelling force is equal to the resultant of the horizontal forces applied to the frame, that is to say :

$$(5) \quad P - X = P - P\left(1 - \frac{OD}{R}\right) = P \cdot \frac{OD}{R},$$

and, from formula (4) :

$$(6) \qquad P - X = T.$$

The driving moment is given by :

$$M = F_1 \cdot OD = P \cdot OD.$$

From (5) and (6) :

$$M = P \cdot OD = (P - X)\, R,$$

or

$$(7) \qquad M = T \cdot R.$$

It follows from this that the work developed by the propelling force, which is given by $L = 2\pi n \cdot T \cdot R$, where n is the number of revolutions of the driving axle, is equal to the work done, given by $L = 2\pi n \cdot P \cdot OD$. This is assuming that between the wheel and the surface over which it rolls there exists sufficient adhesion to overcome T and prevent all slipping between the wheel and this surface. In this supposition, the wheel is a producer of motion having an efficiency

$$\eta = 1.$$

On the contrary, in the case where the adhesion is less than T and where, consequently, the driving wheel slips on the flat rail, the wheel is a producer of motion with an efficiency

$$\eta = 0.$$

When a vehicle with wheels fixed rigidly to their axles runs through a curve, the wheels slip on the surface over which they roll. In this case, before taking the realised efficiency of the driving wheel as being less than 1, it is well to consider the efficiency as being still equal to 1 and the effect due to slipping as a resistance due to the curve.

The driving wheel is thus a propeller which gives an efficiency equal to 1 or equal to 0 depending on whether the adhesion is greater or less than the driving force.

3. *Propellers.* — Consider a propeller

as having a radius R, and an angular velocity Ω and turning in a medium of density ρ, calling T the axial thrust; Q the couple and W the power used; we have [1]:

$$(8)\qquad \begin{cases} T = \tau \cdot \rho \cdot R^4 \cdot \Omega^2. \\ Q = n \cdot \rho \cdot R^5 \cdot \Omega^2. \\ W = n \cdot \rho \cdot R^5 \cdot \Omega^3. \end{cases}$$

The coefficient of thrust τ and the coefficient of couple n have no dimensions and are only functions of the coefficient of pitch γ determined by:

$$(9)\qquad \gamma = \frac{V_0}{R \cdot \Omega},$$

where V_0 is the speed at which the propeller moves in the direction of its axis.

It is evident that the useful work is given by $T \cdot V_0$, assuming that the work done is W, given by the third of the formulæ (8). The two values will not be equal, as the efficiency of the propeller cannot be equal to 1. However, the efficiency η' is given by:

$$\eta' = \frac{T \cdot V_0}{W}.$$

Substituting for T and W the values given by (8), and for V_0 the value which can be obtained from (9) we have:

$$(10)\qquad \eta' = \frac{\tau \cdot \gamma}{n}.$$

The values τ and n are constant for each batch of similar propellers. The variation of the values of τ and n as functions of γ is shown in the curve, figure 2.

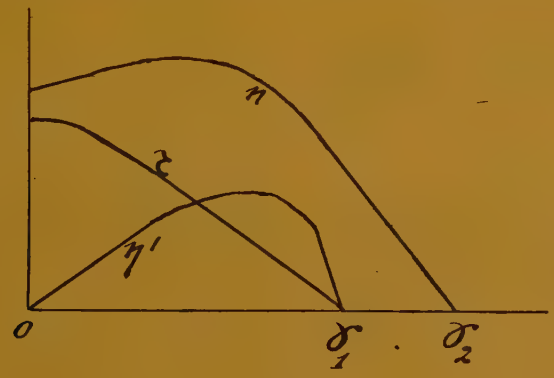


Fig. 2.

This diagram also shows the variations of η', which reaches a maximum and disappears when $\gamma = 0$ and $\gamma = \gamma_1$, corresponding to $\tau = 0$.

The value of γ_1 is smaller than the coefficient of pitch γ relative to the distance travelled through the air H to which it bears the relation:

$$\gamma = 2\pi RH.$$

The value γ_2 of γ for which n disappears on the other hand is greater than γ, and we can therefore write:

$$\gamma_1 < \gamma < \gamma_2.$$

For good propellers the maximum efficiency varies from 0.75 to 0.85.

From this conclusion and the statement made in the preceding chapter, it would appear that the driving wheel is preferable to the propeller for those forms of

[1] See Pistolesi: *Lezioni di Aeronautica*. Edition Vallerini, Pise.

land transport, in which the former can be used.

Let us now see how this conclusion must be interpreted and modified when one takes into account the efficiency of transport and the limits of adhesion.

4. *Efficiency of transport and the efficiency of the means of propulsion.* — Consider a train composed of a locomotive drawing carriages carrying neither passengers nor goods. Let P be the weight of the locomotive, Q the weight drawn. The useful work obtained by this train may be considered as proportional to Q, whilst the work absorbed is proportional to P + Q. The transport efficiency is :

$$\varepsilon = \frac{Q}{P + Q}. \tag{11}$$

When the propelling mechanism consists of driving wheels, the value of P is governed by the value of the tractive effort, because the ratio

$$T < 1\,000\, f P, \tag{12}$$

where P is the total adhesive weight and f the coefficient of adhesion, must be satisfied.

The maximum value of ε is thus given by

$$\varepsilon = \frac{Q}{\frac{T}{1\,000\, f} + Q}. \tag{13}$$

When the propulsion is assured by propellers, the weight P is not governed by the tractive effort given by the ratio (12). In this case, it is convenient to imagine the fitting of a motor driven propeller to a vehicle suitable for passengers and goods, that is to say, similar in construction to a motor vehicle. The value P as introduced in the formula (11) is then composed of the weight of the motor, its accessories and the propeller. The latter is in turn dependent on the power of the motor.

Calling T′ the tractive effort in kilograms V′ the speed in kilometres per hour, μ the weight of the motor and accessories per horse power, we have :

$$P = \mu \frac{T'V'}{270}. \tag{14}$$

Substituting this value in the expression (11) gives :

$$\varepsilon' = \frac{Q}{\mu \frac{T'V'}{270} + Q}. \tag{15}$$

where Q represents the weight of the train, excluding the motor and accessories.

We obtain the overall efficiency of transport, taking into account the transport efficiency proper, in the case of driving wheels, by multiplying the ε given by formula (13) by $\eta = 1$, and in the case of propellers by multiplying the ε' given by formula (15) by η', given by formula (10). The efficiencies finally obtained are as follows :

for driving wheels :

$$\theta = \varepsilon \cdot \eta = \frac{Q}{\frac{T}{1\,000\, f} + Q}.$$

for propellers :

$$\theta' = \varepsilon' \cdot \eta' = \frac{Q}{\mu \frac{T'V'}{270} + Q} \cdot \frac{\tau \cdot \gamma}{n}.$$

One or other method is preferable or the choice is a matter of indifference, in accordance with whether :

$$\theta \gtrless \theta'.$$

or, in other terms according as :

$$(16)\quad \frac{Q}{\frac{T}{1\,000f}+Q} \lessgtr \frac{Q}{\mu\frac{T'V'}{270}+Q}\cdot\frac{\tau\cdot\gamma}{n}.$$

Supposing that $Q = 100$ tons, $V' = 80$ kilometres per hour, $f = \frac{1}{7}$, the resistance r on straight track and on the level will be :

$$r = 6.5 \text{ kgr.}$$

Calculating both sides of the expression (16) in two cases where the gradient of the line is :

$$i = 0, \quad i = 40 \text{ mm. per metre,}$$

when $i = 0$, we have, for the conditions stated :

$$T = r\left(Q + \frac{T}{1\,000f}\right); \quad T = 680 \text{ kgr.}$$

from which

$$\theta = 0.95.$$

Assuming the use of a suitable motor to drive the propeller (an internal combustion engine) and taking for μ a very high value, say 5 kgr. per horse power, for the type of motor suggested, we find :

$$T = 650 \text{ kgr.}$$

$$\frac{\mu T'V'}{270} = 950 \text{ kgr.}$$

For

$$\frac{\tau V_0}{n} = 0.85.$$

it follows :

$$\theta' = \text{about } 0.82.$$

Therefore :

$$\theta > \theta',$$

and it is at once seen that it is better to use a locomotive having driving wheels.

For $i = 40$ mm. per metre, we have for the conditions stated :

$$T = (r + i)\left(Q + \frac{T}{1\,000f}\right);$$

$$T = 8\,700 \text{ kgr.}$$

Therefore :

$$\theta = 0.62.$$

Furthermore :

$$T' = 5\,200 \text{ kgr.}; \quad \mu\frac{T'V'}{270} = 7\,700.$$

When

$$\frac{\tau V_0}{n} = 0.85$$

we find

$$\theta' = 0.77.$$

Therefore $\theta < \theta'$, and it would be preferable to use a propeller as the propulsor.

This example suffices to prove that, for land transport over steep grades the propeller has an advantage over driving wheels.

This is a most important result, for it may lead to a radical change in the methods of working lines in mountain districts.

Of still greater importance is the application of propellers to land transport over grades too severe for adhesion lines.

In the equation

$$T = \left(r + i + \frac{1\,000\,\alpha}{g}\frac{dV}{dt}\right)(P + Q),$$

where α is the coefficient of inertia, g the acceleration due to gravity, $\frac{dV}{dt}$ the derived function of the speed with respect to the time, if one takes $T = 1\,000\,f \cdot P$, we have for the train as specified

$$\frac{dV}{dt} = 0, \quad i_{max} = \frac{1\,000\,f \cdot P}{P + Q} - r,$$

that is, for

$Q = 0$, $r = 5$, $i_{max} = 138$ mm. per metre.

On such a gradient, an adhesion rail car would be able to continue in motion if the whole of its weight were available for adhesion. But this rail car would not be able to start on this grade and there would be an insufficient factor of safety to cover any unexpected variations in the adhesion.

In any case, the vehicle would not be able to ascend any steeper gradient and the driving wheels would give an efficiency of $\eta_1 = 0$. But if one substitutes a propeller for the driving wheels, there is no limit to the gradient which may be ascended. Such a system of propulsion could be adopted in place of that used on funicular railways.

The problem of security remains to be solved, that is to say, the stopping of the vehicles on an inclined plane in the case of the motor failing. This problem can be solved by the application of automatic brakes similar to those used on funicular railways, the action of the tractor cable being replaced by the action of the propeller.

[625 .13 (.493)]

Note on the construction of the Cinquantenaire tunnel on the Schaerbeek-Hal line of the Belgian State Railways,

By L. PÊCHE,
ENGINEER IN CHIEF,
DIRECTOR OF DESIGN AND CONSTRUCTION FOR NEW LINES.

Figs. 1 to 16, pp. 196 to 202.

The CINQUANTENAIRE TUNNEL, which runs underneath *Schaerbeek* and *Etterbeek*, between the Chaussée de Louvain and the Etterbeek-Cinquantenaire station, is the most important work on the new *Schaerbeek-Hal Junction* goods line of the Belgian State Railways.

This line will give a direct route between Schaerbeek and Antwerp for :

a) *Through trains from Hal and beyond;*

b) *Through trains from Baulers and beyond;*

c) *Through trains from Ottignies and beyond.*

Under present traffic conditions, the Operating Department estimate that it can work through the junction, in both directions, 20 Hal trains, 20 Baulers trains and 40 Ottignies trains.

The advantages of these alterations will be as follows, in order of importance :

1. *A reduction of 20 trains in each direction* on the very heavily loaded section Hal-Forest-Midi on the international Brussels-Paris line;

2. *A reduction of 30 trains in each direction* on the Brussels West suburban line, the proposed quadrupling of which will remain in abeyance;

3. *A reduction of 60 trains* at the important centre known as « Pont de la Senne Junction » on the Brussels-Ostend line, a point where 320 trains, of which 180 are passenger, pass daily.

The 60 freight trains mentioned above now interfere with the timings of all the passenger trains on the main Brussels-Ostend line;

4. The diversion of the traffic to and from Ottignies will relieve the Quartier-Leopold station of about 80 freight trains which now pass through it, and this station will be used for « passenger » traffic only.

Further, the important point should be noted that the 80 trains diverted will not interfere with the running of passenger trains on the main lines from Brussels to Antwerp and from Brussels to Liége at the approach to Schaerbeek;

5. Of the 80 trains (in both directions) which will pass through the Cinquantenaire tunnel, half are through trains to and from Antwerp, and will not shunt at Schaerbeek-Formation. Under the present arrangement, these trains have to pass through this station and unnecessarily congest it.

From what has been said, it will be appreciated it is to be regretted that this

line, authorised more than 35 years ago, has only just been opened to traffic. The diagram (fig. 1), shewing the modification in the running of trains as the result of the opening of the Schaerbeek-Hal junction, illustrates clearly the above description.

The CINQUANTENAIRE TUNNEL has a total length of 1 716 m. (1 877 yards). The tunnel is straight with a rising gradient of 1 in 154 in the direction Schaerbeek to Hal.

In 1896, a length of 200 m. (219 yards) of cut and cover was made under the Avenue de Tervueren at the time when this important road was constructed.

In 1910, the Railway Administration placed the contract for the construction of the remaining portion of the tunnel. At the end of 18 months, the contractor, after having tried various methods, had to abandon the work. He succeeded in completing the lining for 228 m. (249 yards) on the Schaerbeek side and for only 53 m. (58 yards) on the Etterbeek side, these portions being under land not built upon at that time.

There therefore remained 1 235 m. (1 351 yards) of tunnel to be constructed.

The *construction* of this first part of the tunnel had shewn sufficiently clearly the difficulties and drawbacks of the undertaking. Exact information had been obtained, not so much of the ground to be dealt with, as this was already known, but more especially of the way it behaved when excavated.

These soils belong to the tertiary group and consist of « ledien », « laekenien » and « Brussels » sands.

From the *engineer's* point of view, there is no difference between the *ledien* and *laekenien*, which consist of calcareous sand, the mass of which is consolidated in continuous layers of sandstone, also calcareous; these sandstones were formerly used for building purposes.

The masonry of the Brussels Town Hall is composed of this sandstone.

The *Brussels* formation consists of calcareous sands and sandstone alternating with quartz sands and sandstone.

The sandstone occurs in continuous layers or in separate masses. The upper Brussels formation is especially calcareous.

All these sands in their natural formation are very compact and can easily be excavated. On the other hand, when they are *decalcified*, they lose their cohesive qualities. They are, so to speak, in an unstable condition and are very ready to continue the settling which has taken place during their decalcification.

We may, it seems, very well compare them to corn in a sack, the least amount of shaking causing them to settle.

In 1924, the Railway Administration invited tenders for the completion of the tunnel, and included in the terms of contract, not only the responsibility of the contractor, but also that of the architect, in accordance with the conditions laid down in articles 1792 and 2270 of the *Civil Code*.

Firms tendering were required to submit a statement completely explaining the method of executing the work and to furnish references.

Finally, much latitude was allowed in the choice of the contractor so as to ensure the one best qualified to bring the work to a successful conclusion being selected.

The essential conditions of the problem were as follows : *To construct a tunnel for double track under a district completely built upon, the tunnel being an almost uniform depth of 10 m. (32 ft. 10 in.) below the street level; the tunnel*

to be made through the ledien and Brussels sands referred to above; the level of the water bearing strata being at least 10 m. (32 ft. 10 in.) below rail level.

From the foregoing, as from the experience of the work carried out in 1910, it will be seen :

1. That any settlement of the headings would have an immediate effect on the buildings on the surface;

2. That the decalcified sand would exert a great weight upon the lining;

3. That it was necessary to limit the dimensions of the excavations so that they might be made good rapidly and effectively in order to reduce to a minimum any settlement, and localise it;

4. That during the lining it was desirable, at any given section, for the ratio of excavation to undisturbed material to be as small as possible, so that the solid sections might support the material above;

5. That it would be very imprudent to construct the side walls by underpinning, owing to the risk of the arch sinking *en bloc*, which would destroy the buildings above;

6. That no precaution was required as regards water, which it was known would not be encountered.

Messrs. Blaton & Fougerolle Bros. proposed to carry out the complete *lining in concrete*, composed of 900 litres (31.8 cubic feet) of gravel, 500 litres (17.7 cubic feet) of sand and 300 kgr. (661 lb.) of cement. This is actually the proportion of « ordinary » concrete in specification XXIII of the State Railways (2 volumes of gravel and one volume of cement mortar) which contains 600 kgr. of cement per cubic metre (1 011 lb. per cubic yard) of sand.

They also proposed to inject systematically *strong cement mortar* behind the lining under a pressure of 4 kgr. per square centimetre (56.8 lb. per square inch).

The *grouting of the tunnel* was carried out by the « *Cement gun* » method, the grout consisting of 370 kgr. of cement per 1 m^3 (624 lb. per cubic yard) of screened sand. Finally, it was stipulated that no timbering was to be left in or behind the concrete.

The section of the tunnel, as constructed, is clearly shewn by figure 7.

The scheme put forward by the contractor only provided footings consisting of a plain wall 0.3 m. (1 foot) thick.

It was recognised that the stability of the work itself did not call for any special type of foundation, seeing that the pressure on the side walls was small and that there was no upward pressure.

The administration, however, *insisted on massive footings* as shewn on the figures, because experience shewed that tunnels with substantial footings gave less trouble as regards upkeep than those without footings, even in compact material.

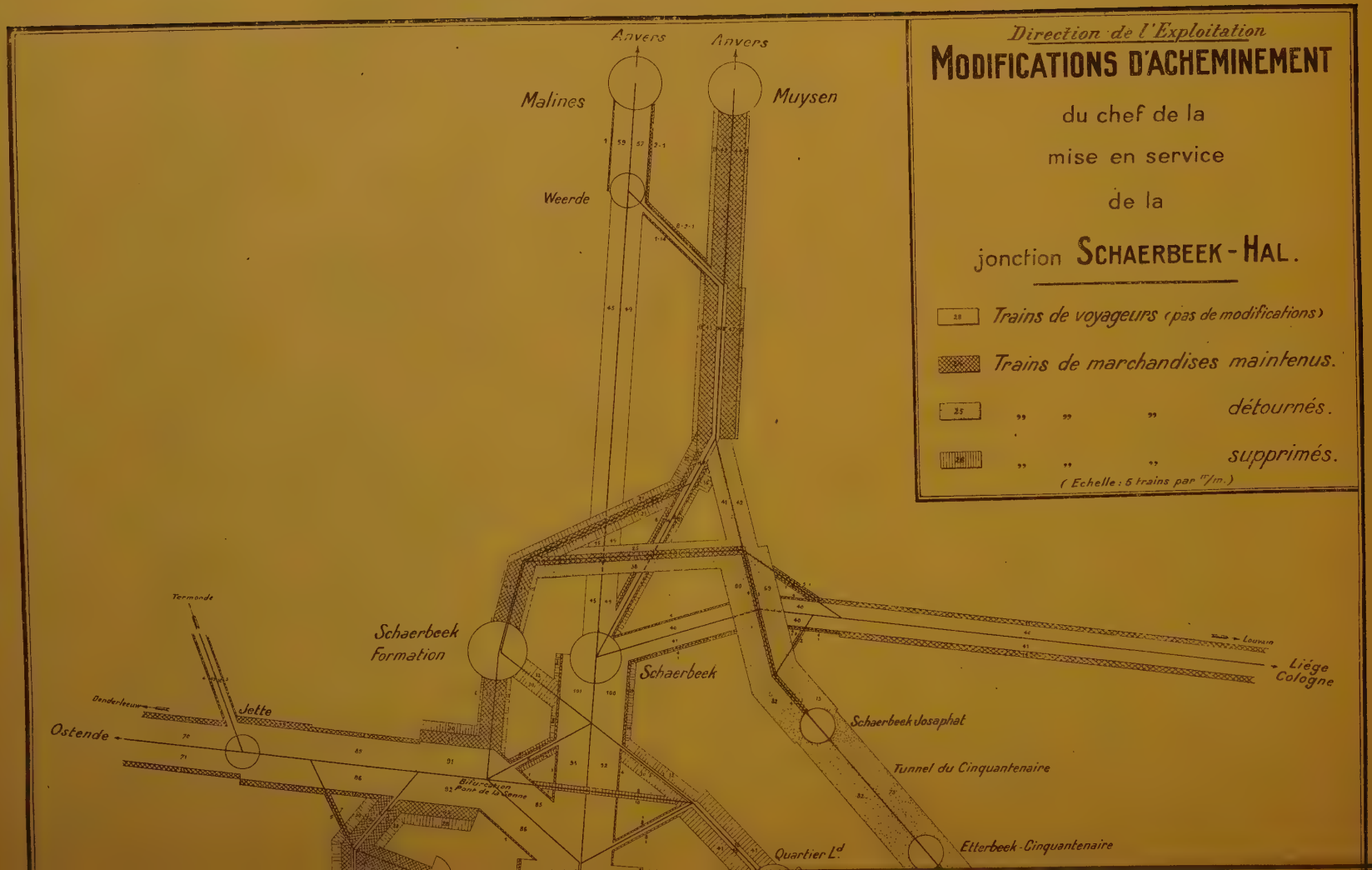
We believe also that these footings, which are integral with the lining, and have a total weight of 80 t. per metre (72 English tons per yard) run, reduce the vibrations due to the passage of heavy trains.

In any case, the contractor agreed to modify his design without increasing the total amount of his tender.

The cost price was 13 000 fr. per metre run.

Method of construction.

We think it may be of interest, in order to make the method clear, to shew diagrammatically the stages of construction.


Direction de l'Exploitation
MODIFICATIONS D'ACHEMINEMENT
du chef de la
mise en service
de la
jonction SCHAERBEEK - HAL.
Trains de voyageurs (pas de modifications)
Trains de marchandises maintenus.
" " " détournés.
" " " supprimés.
(Echelle : 5 trains par m/m.)
Anvers
Anvers
Malines
Muysen
Weerde
Termonde
Schaerbeek Formation
Schaerbeek
Louvain
Liége
Cologne
Denderleeuw
Jette
Ostende
Schaerbeek Josaphat
Tunnel du Cinquantenaire
Bifurcation
Pont de Vienne
Quartier Ld
Etterbeek - Cinquantenaire

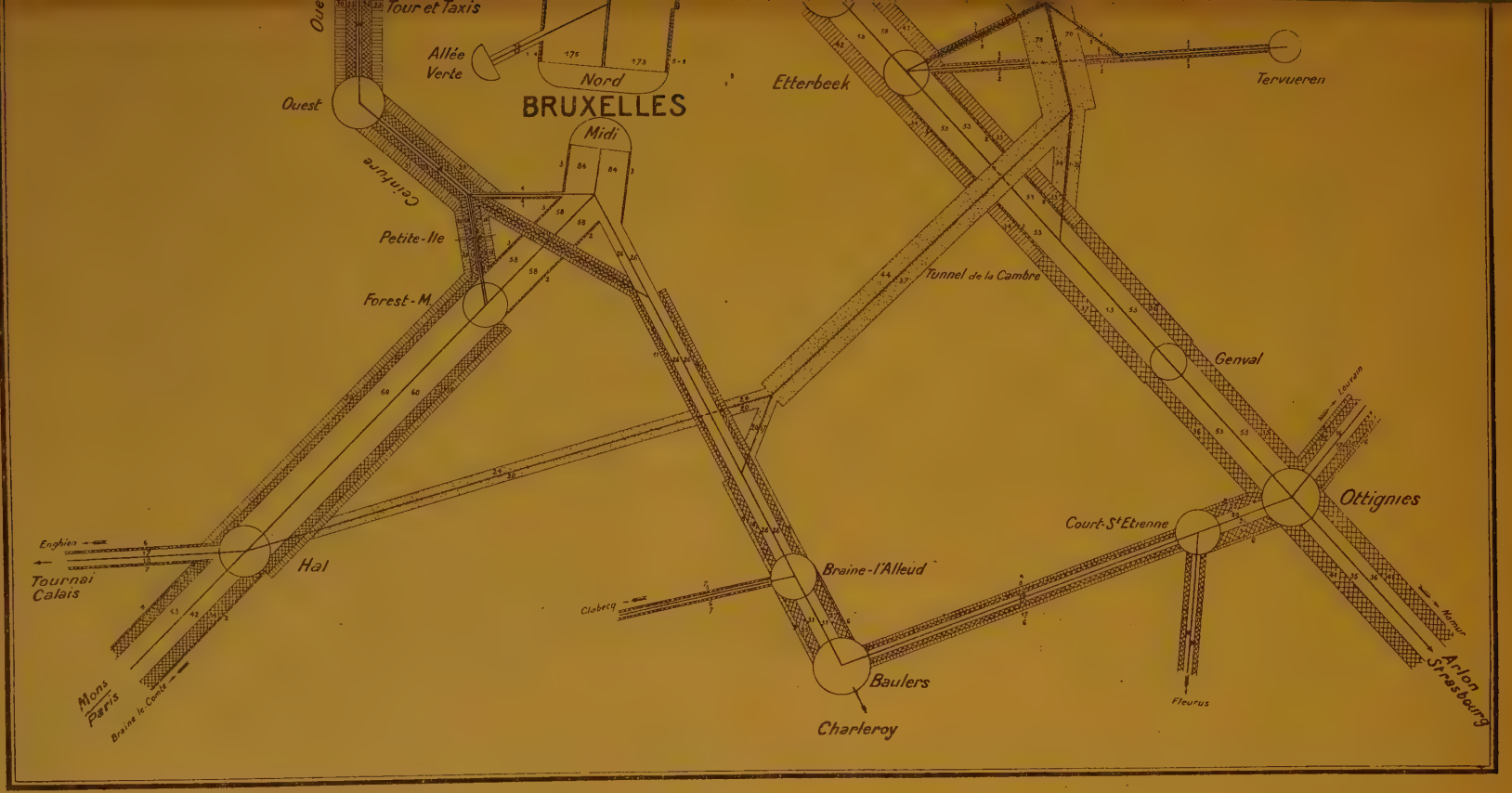


Fig. 1

Explanation of French terms: Direction de l'exploitation = Traffic Department. – Modifications d'acheminement du chef de la mise en service de la jonction Schaerbeek-Hal = Alteration in train routes as the result of the opening of the Schaerbeek-Hal junction line. – Trains de voyageurs (pas de modifications) = Passenger trains (no alterations). — Trains de marchandises maintenus = Freight trains still run. — Trains de marchandises détournés = Freight trains diverted. — Trains de marchandises supprimés = Freight trains cancelled. — (Echelle : 5 trains par m/m.) = (Scale : 5 trains per millimetre).

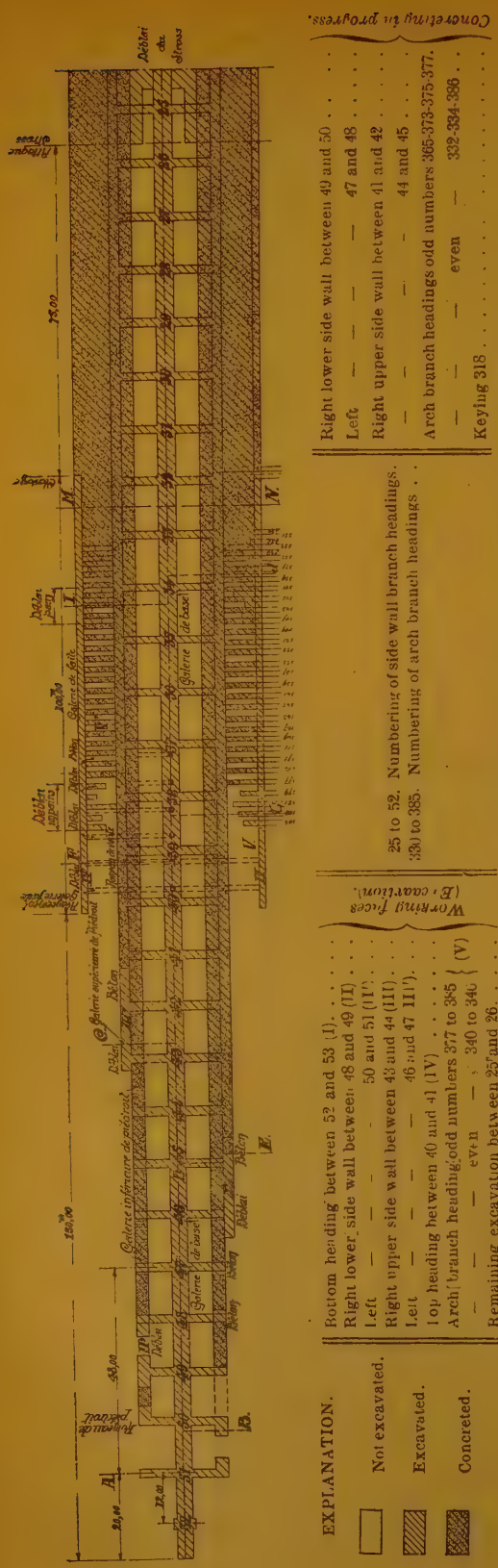

EXPLANATION.
Not excavated.
Excavated.
Concreted.
Working faces (Excavation).
Bottom heading between 52 and 53 (I) . . . .
Right lower side wall between 48 and 49 (II) . . . .
Left — — — 50 and 51 (II') . . .
Right upper side wall between 43 and 44 (III) . . .
Left — — — 46 and 47 III') . . .
Top heading between 40 and 41 (IV) . . . . .
Arch branch heading odd numbers 357 to 385 (V)
— — — even — 340 to 346 (V)
Remaining excavation between 25 and 26 . . . .
Concreting in progress.
Right lower side wall between 49 and 50 . . . .
Left — — — 47 and 48 . . . . .
Right upper side wall between 41 and 42 . . . .
— — — 44 and 45 . . . .
Arch branch headings odd numbers 365-373-375-377.
— — — even — 332-334-336 . .
Keylug 318 . . . . . .
25 to 52. Numbering of side wall branch headings.
330 to 385. Numbering of arch branch headings . .

Fig. 2 — Schaerbeek-Hal line. — Cinquantenaire Tunnel. — Method of construction.

Diagram shewing the layout of the work and the working faces during excavation and concreting.

The various headings are supposed to be driven in a horizontal direction on either side of the centre line of the tunnel (fig. 2).

The *bottom heading*, the dimensions of which are given in figure 11, and the position shewn in figures 3 to 7, is the first to be driven.

At every 12 m. (13.1 yards) this heading is opened out about 0.30 m. (1 foot) on both sides forming break ups for a cross heading, known as *side wall headings*, the dimensions of which are given in figures 8 and 14.

This heading is extended to the outer surface of the masonry, where a shield of reinforced concrete slabs is erected, to form the final shuttering.

As shewn in figure 8, the end of the side heading is enlarged to form the break ups for headings II and II', known as the *lower side wall headings*, in exactly the same way as in the bottom heading break ups for the side headings were made.

All these break ups remain timbered until a frame, composed of logs having a diameter of about 0.30 m. (12 inches) (fig. 3) allow the top sills to be supported thereon, and the side timbers removed, to give entrance to the side heading.

As shewn in figure 2, the portions of the lower side wall headings between the cross headings are excavated in sections, that is to say, the excavation of a heading is only opened out if the opposite side has not been excavated or if the concrete work is completed.

The diagram shews the left hand cross heading 50 to 51 in course of excavation, while that on the right has not been commenced; the right hand cross heading 48 to 49 in course of excavation, while the corresponding left hand portion has been completely concreted.

Like the bottom heading, the *side wall heading* consists of a *top sill* (two pieces bolted together) *an outside concrete wall* (which remains in the excavation) and *inside wooden struts* (see dimensions in figure 3) and a ground sill.

The *top sill* is in *two pieces,* because one of these has to be taken away when the upper heading is excavated, in order that it may not be left in the concrete.

A narrow gauge track runs in the bottom heading and is provided with a turntable at each side heading, which serves a short section of track for removing the excavated soil and for bringing up the concrete.

It will be realised at once that the *progress of the work* in this part of the work *depends entirely upon the rate of advancement of the bottom heading,* because it is only necessary to remove the shuttering a further 48 m. (52 yards), (cross heading 47 to 51) for the number of points of excavation and concreting in the lower side wall heading to be increased.

The upper side wall headings III and III′ (see dimensions in figure 4) are constructed in accordance with the preceding description.

Normally, the work advances continually, the excavation being about 20 m. (22 yards) in front of the concreting, but never less than 12 m. (13 yards) to facilitate removing the excavated material and bringing up the concrete required for the neighbouring side headings.

In no case can the working face of one of the headings be in advance of the concrete work in the lower headings. If the rate of progress is insufficient, by trebling the number of working faces, the amount excavated can be increased.

When the concrete work in the upper heading reaches the bottom side heading, the top sills of the lower heading are removed and replaced by the arrangement shewn in figure 4. After placing the timbering in the cross heading, the lower portion of the side wall opposite to the cross heading can be concreted, this being known as a « *bouchon* ». This work is obviously carried out from the upper heading. In figure 2 it is assumed that for the right hand heading, the excavation has extended to cross heading 43, and the concrete work to heading 41.

For the left hand heading, the excavation is proceeding between 46 and 47, the concreting is proceeding on this side of 45 (the « *bouchon* » of this cross heading can now be concreted).

The advancement of the top heading IV is always behind the concreting of the upper headings.

Its dimensions, form and position are shewn in figure 5. The *sides* are *inclined* to lessen the fall of earth when the struts are removed. It is connected with the bottom heading by shafts 1 m. × 0.70 m. (3 ft. 3 3/8 in. × 2 ft. 3 1/2 in.) and 6 m. (6.6 yards) apart. The excavation of these shafts is carried out in advance in good ground to avoid any delay in the progress of the work. In the decalcified sand they are of necessity excavated after the heading has been made. It may also be noted that the starting places for these shafts in the bottom heading had been prepared when this heading was cut. For this purpose three top sills were formed of three pieces held together by straps, the middle portion being taken out before beginning to excavate the shaft.

These shafts allowed the excavated material to be removed, and concrete to be brought up, and served to ventilate the heading.

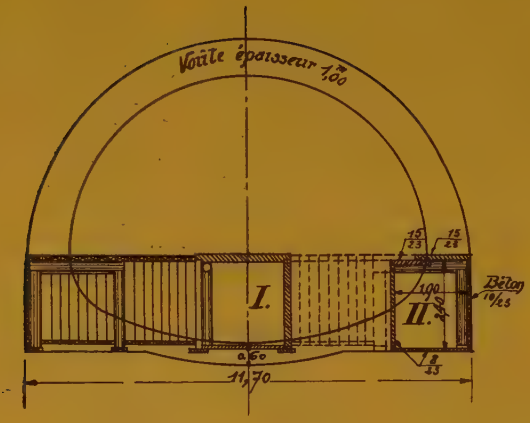


Fig. 3. — Section AB.

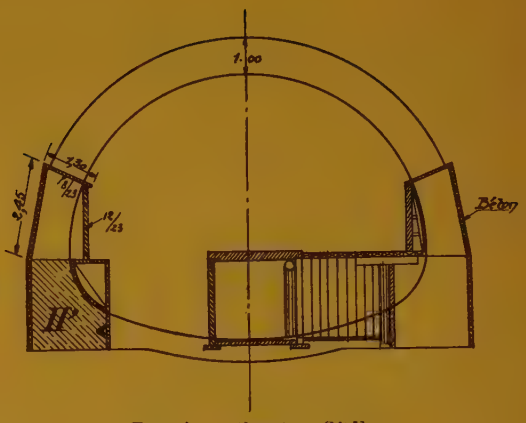
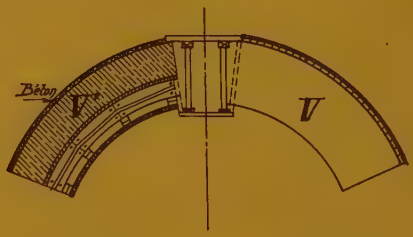


Fig. 4. — Section CDE.

Fig. 6. — Section I. J.



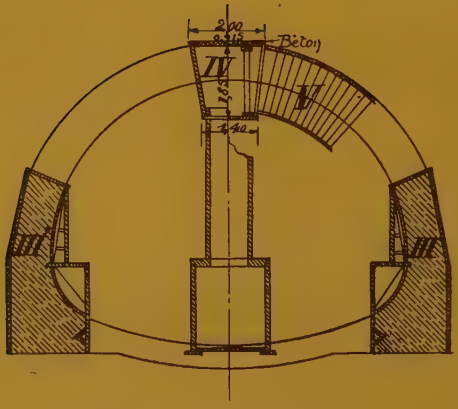


Fig. 5. — Section F. G.

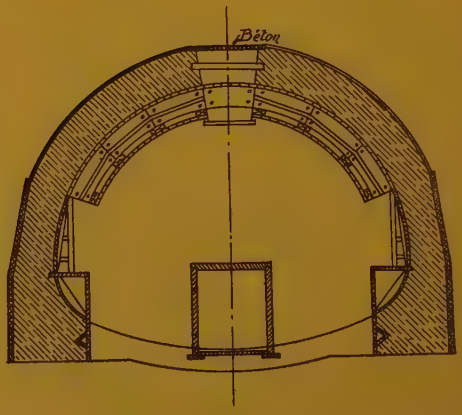


Fig. 7. — Section MN.

Figs. 3 to 7.

Explanation of French terms on this and the opposite pages : Voûte épaisseur 1ᵐ00 = Arch 1ᵐ00 (3 ft. 3 3/8 in.) thick. — Béton = Concrete. — Rameau = Branch heading. — Galerie de base = Bottom heading. — Pince = Strap. — Clameaux = Cleats. — Masque = Shuttering.

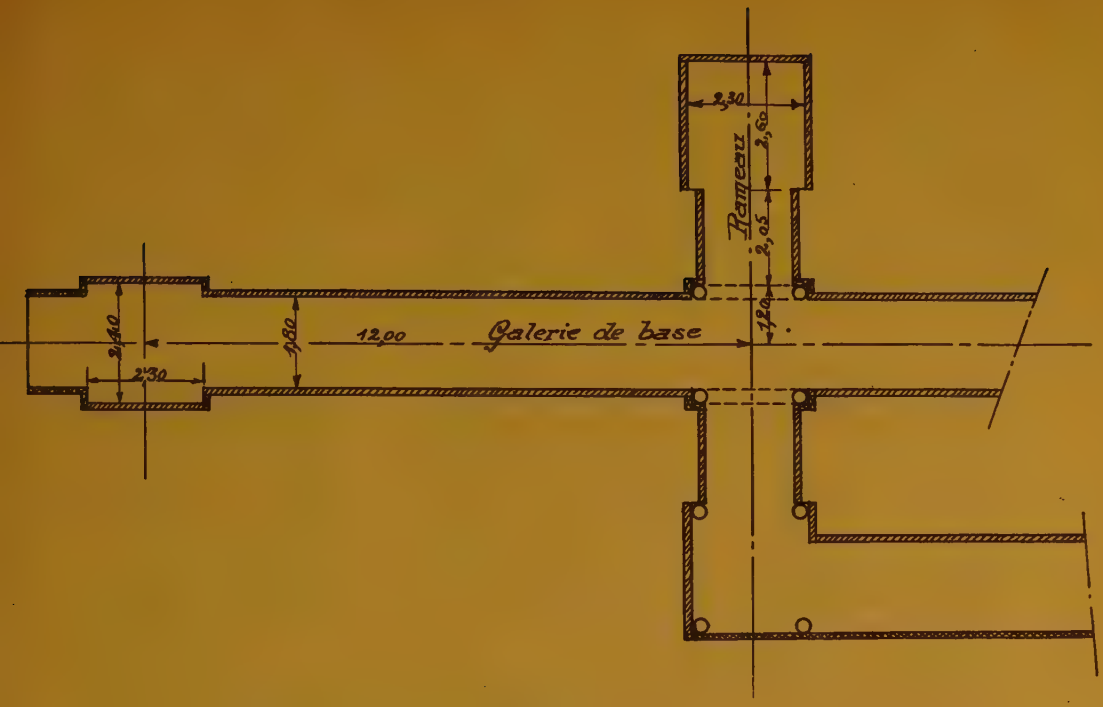


Fig 8.

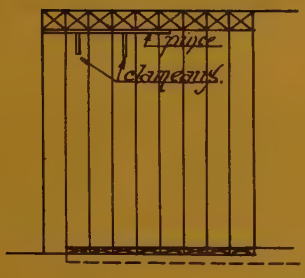


Fig. 9.
Excavation in good ground.

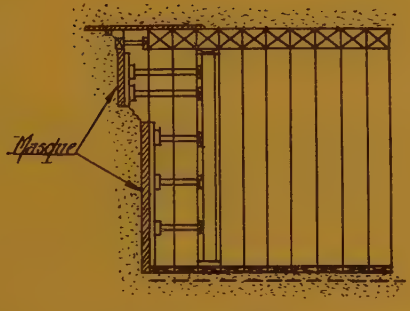


Fig. 10.
Excavation in difficult ground.

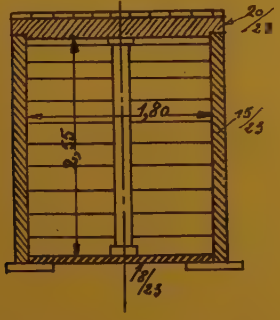


Fig. 11.
Bottom heading.

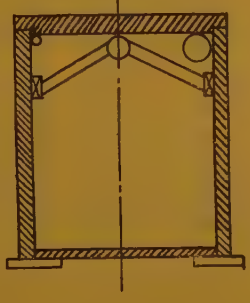


Fig. 12.
Shoring for base heading.

The arch itself is built in rings 1.20 m. (3 ft. 11 1/4 in.) wide, known as arch sections. Their dimensions are given in figure 16.

It will be noticed that the framing is identical as regards its arrangement with that for the other headings.

In good material, these side headings are cut alternately, commencing by the odd numbers, that is to say, in the series shewn in figure 16; 1, 3, 5 and 7 would be taken in hand.

To open out heading IV laterally, it was necessary to support the top sills on a framing carried by struts and foot blocks, as shewn in figures 5 and 6.

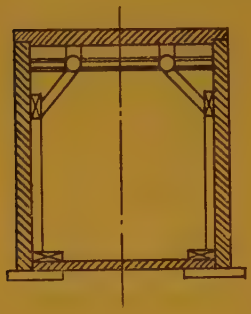


Fig. 13. — Shoring for base heading.

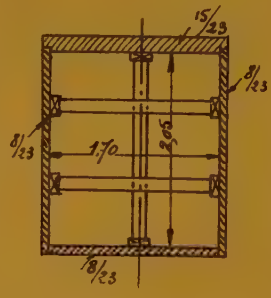


Fig. 14. — Side branch heading.

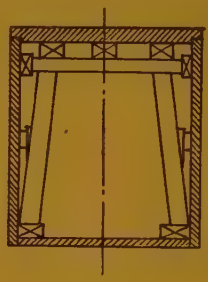


Fig. 15. Shoring.

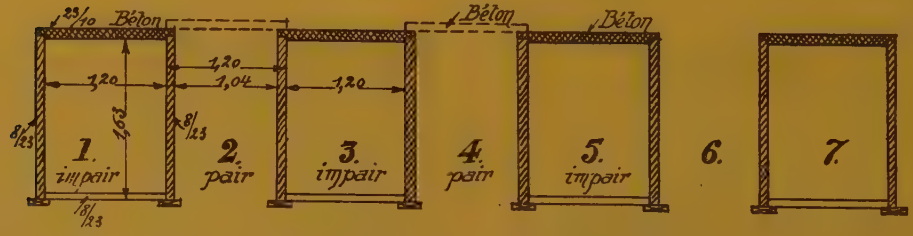


Fig. 16. — Section of arch cross headings.

Explanation of French terms : Béton = concrete. — Impair = odd. — Pair = even.

After the excavation is completed, a centreing is put in, and the cross headings concreted. It is not until after the concrete has completely set that sections 2, 4, 6 and 8 can be excavated and concreted.

The ratio of excavated to unexcavated material along the tunnel is therefore 1/2. In bad material it was realised quickly that it was prudent, and even necessary, to reduce the amount excavated still further. By excavating 1, 7, 13, etc., the amount removed is only one quarter of the length. After concreting these sections, 3, 9, 15, etc., are taken in hand. It will be easily understood that the work was necessarily slowed down because the removal of the excavated material and the bringing up of the concrete could not be done quite so methodically.

On the other hand, the keying of the

arch cannot follow too closely on the concreting of the side walls. Moreover, when the centreing rests on unstable material, there is some risk of it sinking and causing fractures at the junction of the arch with the side wall.

In all places where bad ground was encountered, as the concreting was carried on in the side headings, key pieces of reinforced concrete 20 cm. × 20 cm. (about 8 × 8 inches) were laid as shewn in figure 7, these being built into the concrete.

If for any reason the progress of the main heading was not sufficiently rapid compared with the progress in other headings, by excavating from other points of the bottom heading the number of working faces could be trebled.

The removal of the remaining material followed about 75 m. (82 yards) behind the completion of the concrete. Care was taken that the concrete arch keying was at least 20 days old. As a rule, the small headings remained in good order. They remained open for a few days only, as the concreters followed close behind the excavators, except in the bottom heading and the side wall heading which were only used for removing the excavation and bringing up material, and had to remain under load on the average about four months. For this reason they had to be shored up at a number of places. Figures 12, 13, 14 and 15 indicate the arrangement of shoring.

Method of excavation. — As will have been noticed, all the headings are of *different forms and dimensions appropriate to the particular work to be carried out.* Their shuttering is, on the other hand, identical in principle, if not as regards dimensions : *one top sill, two struts and a bottom sill.* The method of excavation is the same on all the working faces, and it will be sufficient to indicate the method followed in the bottom heading.

In good ground (fig. 9) work is carried out over the *total width of the top sill,* that is, 0.23 m. (9 inches). Care is taken that the excavation is of the exact profile to avoid empty spaces behind the shuttering. The top sill is put in place, bolted up and held temporarily by two iron straps carried on cleats. The two side struts are then put in place on foot blocks, and the framing completed by the bottom sill. The excavators working eight-hour shifts can put in eight to nine of these frames per shift. The daily rate of progress may be as much as 6 m. (6.6 yards).

In difficult ground (figs. 10 and 11) *the working face is* more or less completely *close boarded,* in accordance with the nature of the material, *by planks,* supported by struts bearing on a vertical post, commonly known as a *soldier.* The excavation for placing the top sill is carried out under the protection of horizontal pieces driven into the ground and supported on the last top sill. These pieces consist of planks in headings I, II and III, where they may be recovered after removing the wooden top sill. They are put in place beginning at the centre of the heading.

On the other hand, in headings IV and V, where the concrete top sills remain behind the concreting, they consist of iron plates, with drilled holes in staggered rows, which allow the plates to be pushed forward by pressure exerted from the last top sill put in position, by means of a pinch bar, the end of which is placed in the holes. The same plates therefore may be used during the whole progress of the work.

From the preceding description, it will be clearly seen that, as regards the exca-

vation in the headings, thanks to the arrangements adopted, the work has been standardised, with good results as regards the output of the men.

After a relatively short time, the workmen were able to construct a satisfactory timbering and at the same time prevent card falls.

Concrete work. — The concrete was mixed inside the tunnel with a « Roll » concreter. The correct quantities of gravel and sand were measured out at the Stores thanks to the use of wagons with suitable partitions. The result was that supervision was easy, the man in charge at the concreter had to check the cement used only. The concrete mixture was *very wet*. The work in the side wall headings could be easily supervised, as the number of working points was relatively small.

On the other hand, in the arch headings the working points were more numerous and the work had to be very carefully done; but the method of doing the work enabled us to exercise constant supervision, because the excavation of the even headings revealed the concreting in the odd headings. The concreting of the top of the arch, being particularly difficult, was specially supervised. Moreover, as the concrete was brought up by 10 litre (2.2 gallon) buckets, the workmen were able to make a good job of it. The concreting was carried out in successive layers well rammed, as far as possible following the radii of the arch, and not horizontally.

After the *completion of the timbering* (the invert excepted) the remaining excavation could be removed without difficulty. If figure 7 were completed by the concreting of the top of the arch, it would shew very well the working face for removing the remaining excavation. It shews the bottom heading, the remainder of the upper and lower side wall headings with their timbering, and the centreing for the arch.

After the excavation was completed, the « cement gun » was brought into operation and injections of cement made methodically behind the arch. For this purpose, iron pipes had been built in the concrete of the arch beforehand.

These injections were carried out at certain points behind the reinforced concrete shuttering of the headings shortly after the work was started, the most important application being made about 80 m. (87 yards) from the entrance. At this place the arch cross headings penetrated a seam of surface clay, which formed a pocket containing water. Injections were made at this place when the headings were first driven, and were repeated after concreting, 15 000 kgr. (33 070 lb.) of cement having been used.

When this difficult point had been passed we felt satisfied that the work would be completed under perfect conditions as regards the tunnel itself.

Unfortunately a number of buildings above and close to the tunnel suffered more or less serious damage. There were no accidents to the staff, the few falls of earth in the tunnel being unimportant.

The work was estimated to take 600 days for its completion. In the original scheme it was proposed to drive the tunnel entirely from the Schaerbeek end, as it was easier to dispose of the excavation and to bring up Stores than on the Etterbeek side. Working from both ends also necessitated double equipment. However, to gain time, some work was done from the Etterbeek end.

The bottom heading towards Schaer-

beek was commenced on the 6 October 1924, and that towards Etterbeek on the 2 July 1925. The two headings met on the 13 January 1926 at 1 055.85 m. (1 155 yards) from the Schaerbeek end.

The concreting, begun on the 2 December 1924, was completed, invert included, on the 23 April 1926. The work took two months less than the estimated time which, having regard to the nature of the work, its importance and the difficulties which occurred, was already short.

The amount of earth excavated was 102 000 m³ (133 400 cubic yards); 37 300 m³ (48 800 cubic yards) of concrete were used.

The work took about 2 000 m³ (2 600 cubic yards) of timber. This timber was used again about three times.

The average output per man for an eight-hour day was as follows — for excavating, timbering and loading up :

	Section area.		Output.	
	Square metres.	Square yards.	Cubic metres.	Cubic yards.
Bottom heading (I)	5.11	6.11	1.100	1.440
Side wall heading	4.18	5.00	0.750	0.980
Lower side wall heading (II and II')	5.18	6.20	0.950	1.240
Upper side wall heading (III and III')	2.87	3.43	0.800	1.050
Top heading (IV)	3.54	4.23	0.650	0.850
Arch branch heading (V)	2.16	2.58	0.850	1.110
Remaining excavation	36.64	43.82	5.300	6.930
Invert	4.15	4.96	4.500	5.890
Total section	82.36	98.51	1.500	1.960 about.

[625 .142.4]

Reinforced concrete sleepers (Gaudin's Pattern), (1)

By Mr. WEILER,
GENERAL MANAGER OF THE NANTES TRAMWAYS COMPANY.

Figs. 1 to 8, p. 207.

(From *L'Industrie des Voies ferrées et des Transports automobiles.*)

Railway Civil Engineers are constantly considering how to improve the line so as to get a solidly laid track which will stand up well and give good running, and thereby obtain safety and economy whilst satisfying the needs of the travelling public.

In order to attain the desired end, they have devoted great attention to the way the rails are carried : for a long time wooden sleepers placed 0.80 m. (2 ft. 7 1/2 inches) apart have been used to support the rails.

Such sleepers have given good results and have been used on lines over which trains of constantly increasing speed and weight are run. The life of such sleepers, however, is limited and the timber from which they are cut is becoming scarce and expensive.

Metal sleepers have also been used with good results, although they get out of shape and rust fairly rapidly when laid in wet positions. Their cost is also on the high side.

Ever since the invention of reinforced concrete attempts have been made to make reinforced concrete sleepers, as this material is little affected by the atmosphere.

Many types have been manufactured, but in service the sleepers were found to be heavy and difficult to handle : the rail fastenings were usually not sufficiently secure for safety, and the sleepers were too rigid. The concrete was also found to break up under vibration.

Mr. Gaudin, an Engineer in the Public Works Department, has designed a sleeper which appears to have overcome all these disadvantages.

This sleeper (figs. 1 to 8) is in the form of an inverted U, the ends of the legs being stiffened along their outer edges by a flange which widens the bearing of the sleeper without appreciably adding to its weight.

In section, the sleeper measures 0.20 m. (7 7/8 inches) in width at the top, and 0.30 m. (11 13/16 inches) at the base, including the flanges, and is 0.15 m. (5 7/8 inches) high.

Under the rails the section is solid for a distance of 0.27 m. (10 5/8 inches) outside the rail, and 0.55 m. (1 ft. 9 11/16 in.) inside. As the length is 2.40 m. (7 ft. 10 7/16 in.) the hollowed-out part at the centre is 0.82 m. (2 ft. 8 1/4 in.) long and at each end 0.17 m. (6 11/16 inches).

Mr. Gaudin has in this way been able to make a sleeper which is light in weight, it weighs less than 160 kgr. (352 lb.), so that it can be easily lifted

(1) Paper read at the IIIrd general technical meeting of the *Union des Voies ferrées et des Transports automobiles*, Lyons, 22-24 October 1925.

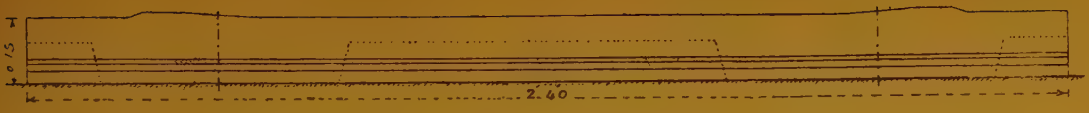


Fig. 1. — Type of sleeper for normal gauge.

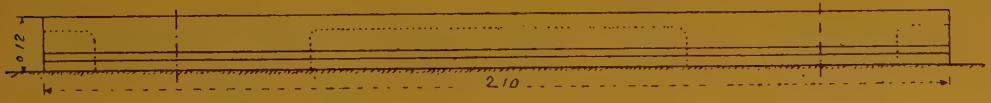


Fig. 2. — Type for 1.45 m. (4 ft. 9 1/16 in.) gauge tramways.

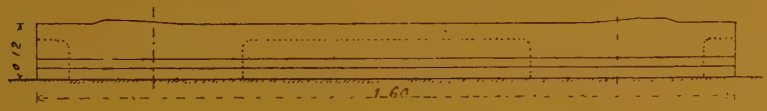


Fig. 3. — Type for metre (3 ft. 3 3/8 in.) gauge.

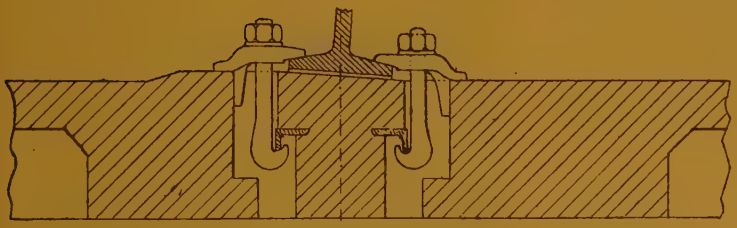


Fig. 4.
Longitudinal section.

Fig. 5. — Section
at the axis of the rail.

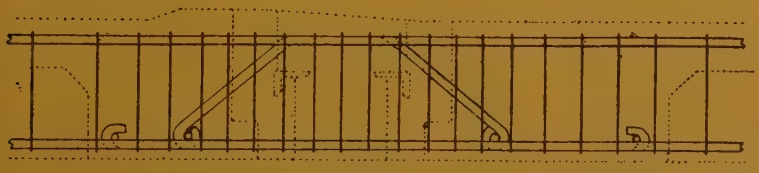


Fig. 6.
Elevation of reinforcement.

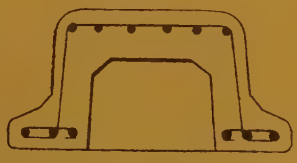


Fig. 7. — Section
at the centre of the sleeper.

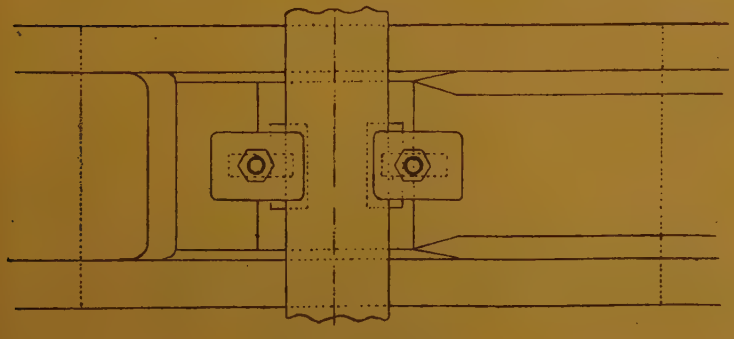


Fig. 8. — Plan.

Figs. 1 to 8.

and carried by three or four men. The inclination of the rails is obtained by the bearing surface being cast at the proper angle.

The sleeper is properly reinforced and is very strong.

Longitudinally, the reinforcement consists of 6 rods, 8 mm. (5/16 inch) diameter, at the top, and of 6 rods, 7 mm. (9/32 inch) diameter at the bottom. The ends of the rods are turned up in the form of a hook.

Transversly, pieces of wire 4 mm. (5/32 inch) diameter bent into the shape of an inverted U are placed at varying calculated distances apart. The solid part of the sleeper under the rails is also strengthened by cross bars which hold the concrete in a rigid frame, and the whole reinforcement when embedded in the concrete forms a support able to carry heavy loads.

In addition, four reinforcing rods, bent at the ends into half circles, are provided under the upper longitudinal rods to key and lock together the concrete between the expansion joints provided in the upper face of the sleeper.

They also localise any defects resulting from bending caused by bad tamping of the sleeper at the expansion joints. These joints are made by inserting tarred paper at right angles to the longitudinal rods in the concrete above them.

It will be appreciated that when the sleeper is supported at its centre, the joints will give when a train runs over the sleeper, and close up when it has passed, owing to the elasticity of the reinforcing rods without causing the concrete to crack. The play is of course only some tenths of a millimetre.

The sleeper thereby obtains the flexibility usually lacking when reinforced concrete is used.

The rail is held down by means of a bolt with a hooked end which engages under the web of an angle cast in the concrete, and a holding down plate, the heel of which bears on the sleeper and the toe on the bottom flange of the rail.

The plate has a projection which fits into the opening provided in the sleeper for the holding down bolt, and which prevents any horizontal movement of the plate and thereby any alteration in the gauge.

This holding down plate is unlike the usual clip plate, as it has a heel which is carried back beyond the projection to give a good bearing on the sleeper, and to reduce the pressure *per square inch* on the concrete when the bolt is tightened up.

This method of fastening down is strong, and when used the rails can be laid easily and quickly. Once the rails are placed on the sleepers, and the bolt and projection of the holding down clip plate entered in the hole, taking care that the hook engages with the angle, there is nothing more to do but tighten up the nut. With this arrangement the rails of a track can be removed and replaced without moving the sleeper or disturbing the ballast.

So far as resistance to transverse movement is concerned, it is provided against most efficiently. The hook of the holding down bolt when held by the angle embedded in the concrete is a fixed point, and any horizontal movement of the rail would necessitate the displacement of the clip plate and the lengthening of the bolt. The bolt, and with it the clip, therefore helps to resist any such movement, diminishes the pressure exerted by the projection in the holding down clip plate against the opening in the sleeper, and gives every guarantee against horizontal thrust.

Mr. Gaudin's sleeper was originally designed for use on standard gauge lines with axle loads of 19 t. : the transverse section can carry 650 Kg.-M. (4 700 foot-pounds) where solid, and 1 400 Kg.-M. (10 125 foot-pounds) where hollowed out. It has been under test for some years and has given complete satisfaction.

Mr. Gaudin has since made sleepers for metre gauge (3 ft. 3 3/8 in.) railways

and tramways of 1.45 m. (4 ft. 9 1/16 in.) gauge.

For the metre gauge the sleeper is 1.60 m. (5 ft. 3 in.) long, 0.14 m. (5 1/2 inches) wide at the top, and 0.21 m. (8 1/4 inches) at the bottom where it rests in the ballast.

The solid part under the rail is 0.40 m. (1 ft. 3 3/4 in.) long. At each end it is hollowed out for a length of 0.07 m. (2 3/4 inches) and at the centre for 0.60 m. (1 ft. 11 5/8 in.).

The reinforcement is the same as for the standard gauge sleeper except that the rods are 6 mm. (1/4 inch) in diameter. The same fastening is used.

These sleepers have been tested near Nantes on the line from Nantes to Legé, belonging to the French Narrow Gauge Railways Company, for the last two years, and are behaving very well. They weigh 60 kgr. (132 lb.).

The sleepers for tramways of 1.45 m. (4 ft. 9 1/16 in.) gauge are 2.10 m. (6 ft. 10 5/8 in.) long and of the same transverse section as those for the metre gauge. The same method of reinforcing them and the same rail fastening has been used as in the other cases. They weigh 86 kgr. (190 lb.).

The Nantes Tramways Company, for whom this sleeper was designed originally, has recently put into service 200 of these sleepers under flat bottomed rails weighing 30 kgr. per metre (60.5 lb. per yard) laid alongside the roads and carrying fairly heavy traffic.

Figures 1 to 8 are longitudinal and transverse sections and a plan at the rail.

[621 .392 (.73) & 625 .143.4 (.73)]

Welding battered joints has proved economical.

Figs. 1 to 7, pp. 217 and 218.

(*Railway Engineering and Maintenance.*)

The reconditioning of rail in track by the building up of battered and chipped joints by the welding process has proved so successful, from the standpoints of both cost and service, that it is coming into extensive use on the railroads of America. As is well known, the principal cause for the removal of rail in important main line tracks, aside from the necessity of providing heavier sections to meet the demands of increased traffic, has been the battering of the ends of the rails, thus causing rough riding track on rail that is otherwise satisfactory. Before the introduction of welding the methods by which such rail has been made serviceable for use in main lines or important secondary lines has been either by sawing off the battered ends or re-rolling the rail, which processes involve several handlings of the material, transportation to and from the mills and loss of material from cropped ends, aside from the cost of the sawing or re-rolling itself.

With the rapid increase in the practice of building up rail by the welding process a résumé of what is being accomplished and the methods pursued on the large mileage of roads on which this method is in vogue will not fail to be of interest to all who have to do with the maintenance of track. To obtain this information, questionnaires were

sent to 46 of the larger roads of the country with 187 700 miles of lines asking as to the extent to which the work is being carried on and the results obtained, together with such other available data, based on their experience, as would be of interest. Replies were received from all but two of the roads, the replies covering 176 000 miles of lines.

Early work in welding joints.

The application of welding to the building up of worn frogs and crossings on the steam roads dates back to 1913 when the Southern Pacific (Pacific System) repaired by this process two track crossings located in busy industrial tracks. Its avantages for this class of work were so obvious that in the next few years it came into extensive use. The application of the process to the building up of battered and chipped ends of rails in track appears to have been begun by the Central of Georgia in the latter part of January 1917, and it was being used on that road when the railroads were placed under federal control. The resulting economies were so great that B. L. Winchell, director of the Southern region for the Railroad Administration, issued a circular in July 1918, calling attention to the method and outlining its advantages, the circular arousing much interest in the subject and eliciting many requests for further information. During 1918 the Southern Pacific (Pacific System), faced with the labor shortage and high prices due to the war, extended the welding process to the repair of battered joints and in that year built up 5 000 joints in track, with such satisfactory result that at the present time each operating division has a gang of welders consisting of from 2 to 14 men engaged in this work.

During 1918, the Atchison, Topeka & Santa Fe and the Atlantic Coast Line inaugurated the practice and it was adopted by the Union Pacific in the following year. Other roads put the method into operation, after periods of experimentation, the greater number of them during the past four or five years, until today it is being used on roads with an aggregate road mileage of about 124 000 on which the records show that approximately 2 200 000 joints have been built up at an average cost of $1.48 per joint. These figures are admittedly incomplete since a number of the roads have not kept cumulative records of the joints repaired. In addition, the Boston & Maine, the Southern and the Wabash, with 13 000 miles report that they are now considering the matter. Still other roads with a mileage of 21 500 report that they have built up joints in the past but are not doing so now, while other roads with 17 700 miles report that they have done nothing in this respect. Roads with a mileage of approximately 13 000 have furnished either full or partial data with the request that their identity be not disclosed and their mileage and the number of joints treated have been included in the totals shown above.

No injury to rail results from welding.

When this method was first introduced many doubts were expressed as to the safety of the process, there being a general fear that the heating necessary to make the welds would have an injurious effect upon the molecular structure of the rail. The same doubt as to the safety of welding has also been expressed when the gas welded bond was introduced in track circuits for signaling. The careful inspection of the behavior of the welded rails in service, supplemented by laboratory tests, has failed to support these fears when the work has been done properly and confined to that portion of the rail within the limits of the angle bars, this limitation being practically universal on the roads which are building up joints. This freedom

from failure when the welding of joints is confined to the limits of the angle bars confirms the observations of the Committee on Rail of the American Railway Engineering Association which investigated and reported on the effects of gas welded bonds on rails in 1925, and which stated as its conclusion that « rail breakage appears to be confined to cases in which the bonds have been welded to the web or the base of the rail outside of the joint structure ».

In the early use of the welding process some driver burns outside the ends of the angle bars were built up, and while there is no record of any failures on this account it appears to be the general conclusion that it is not safe to do this, and the rails so built up have been replaced as a matter of precaution and the practice discontinued. Another practice which has been discontinued is that of burning bolt holes through the web of the rail to avoid drilling, since rail end failures have been traced directly to rails where this had been done and investigations have showed that incipient cracks were present around the burned holes. As an explanation of this condition the theory seems sound that the expansion and contraction in the metal surrounding the hole set up stresses which cause the cracks, while the ends of the rails, being free to expand and contract without restraint, were free from such stresses.

All of the roads reporting state that they have found no evidence of injury to the rail from welding when proper precautions are followed. The Union Pacific states there have been no rail failures due to welding since 1921, when a special welding steel was adopted. The Minneapolis, St. Paul & Sault Ste. Marie insists that the flame of the torch be kept from direct contact with the angle bars. The Atchison, Topeka & Santa Fe confines welding to within 12 inches of the rail end, while the Central of Georgia states that it has found no evidence of injury to rails from welding and has taken no special precautions against such a condition. The Chicago, Burlington & Quincy, in order to satisfy itself as to the influence of welding on rail end failures, has issued instructions that in the event of a rail end failure or bolt hole break the failed rail report must show whether or not the rail end had been welded and during the period of a year since these instructions were issued no such breaks have been reported on welded rails.

The processes used.

The welding may be done either by the oxy-acetylene torch or the electric arc. All but two of the roads engaged in building up joints use only the oxy-acetylene process. The only exceptions reported are the Southern Pacific (Pacific System) which, in addition to numerous oxy-acetylene outfits has two semi-portable electric outfits which are used primarily for building up joints on track in paved streets and it now has under construction two modern electric machines, mounted on flanged wheels, and capable of traveling to remote sections of its lines. The Western Pacific, which has used both the oxy-acetylene and the electric process, is now using the latter exclusively.

As may be expected the cost of welding ranges between rather wide limits from a minimum of about $1 per joint to a maximum of $2.88 in some exceptional cases, although the tendency is now to change out the rails when the cost of building up the joints will amount to $2.50 or more. The amount of work done, as well as the organization of the forces naturally has an influence on the cost and on the roads which are doing the work on an extensive scale the range is between $1 and $1.75, with a weighted average for these roads of $1.38. On the Southern Pacific

Data from various roa

NAME OF ROAD.	Mileage.	Are joints welded?	How many years?	Method used.	Number of joints welded.	How are joints selected?	Is work done out of face?	Minimum amount of batter welded (in inches)
Atchison, Topeka & Santa Fe. . . .	12 043	Yes.	8	Oxy-acet.	120 000 in 1925.	Inspection.	Yes.	1/16
Atlantic Coast Line.	4 931	Yes.	8	Oxy-acet.	No record.	Chipped ends.	No.	
Baltimore & Ohio.	5 197	Yes.	1	Oxy-acet.	3 000	Inspection.	No.	1/16
Boston & Albany	404	No.						
Boston & Maine.	2 248	No.						
Buffalo, Rochester & Pittsburgh .	602	Yes.	2	Oxy-acet.	2 000	Inspection.	No.	
Central of Georgia	1 921	Yes.	9	Oxy-acet.	11 500	Inspection.	No.	
Central of New Jersey.	691	No.						
Chicago & Alton	1 052	Yes.	1	Oxy-acet.	6 400	Inspection.	Yes.	1/16 to 1
Chicago & Eastern Illinois	945	Yes.	4	Oxy-acet.	20 000		Both.	
Chicago & North Western	8 457	Not now.	5	Oxy-acet.	30 090	Inspection.	Both.	
Chicago, Burlington & Quincy. . . .	9 404	Yes.	5	Oxy-acet.	95 000	Inspection.	Yes.	1/16 o chippe
Chicago Great Western.	1 496	Yes.	3	Oxy-acet.	2 500	Inspection.	Not as a rule.	
Chicago, Milwaukee & St. Paul . . .	10 784	Not now.		Oxy-acet.	4 or 5 mi.		Yes.	
Chicago, Rock Island & Pacific . . .	7 564	Yes.	2	Oxy-acet.	6 000	Inspection.	No.	1/16
(Western Road).	2 000	Yes.	5	Oxy-acet.	70 000		No.	
Colorado & Southern	1 057	Yes.		Oxy-acet.				
Delaware & Hudson.	895	Yes.	4	Oxy-acet.	700	Inspection.	No.	1/8
Delaware, Lackawanna & Western.	993	No.						
Denver & Rio Grande Western. . .	2 577	Not now.		Oxy-acet.	6 000	Inspection.	No.	
Erie (New York Region)	1 290	Yes.	2	Oxy-acet.	No record.	Inspection.	No.	3/16
Erie (Ohio Region)	677	Yes.	3	Oxy-acet.	15 000	Inspection.	Partly.	
Gulf, Texas & Western.	992	Yes.	2	Oxy-acet.	2 500	Inspection.	Yes.	
Great Northern.	8 222	Yes.	5	Oxy-acet	210 000	Inspection.	No.	1/16
Illinois Central	6 887	Yes.	5	Oxy-acet.	125 000	Inspection.	No.	
Lehigh Valley.	1 364	Yes.	4	Oxy-acet.	500	Chipped ends.	No.	
Long Island.	397	No.						
Louisville & Nashville	5 038	No.						
Maine Central	1 662	No.						
Minneapolis, St. Paul & Sault Ste. Marie.	4 404	Yes.	4	Oxy-acet.	16 000	Inspection.	No.	1/16

elding battered joints.

Organisation.			Results of work.	Increase in life of rail.	Any evidence of injury to rail?	Cost per joint including labor and material (in dollars).	*Remarks.*
(h = helper).	System or division.	Number of gangs.					
1 h		40	Very satisfactory.	25 % in first position.	No.	1.26	Gangs are assigned to each assistant general manager territory.
4-h	Division.	3	Generally satisfactory.	Undetermined.	No.	0.40 to 0.50	
1-h	Division.	8	Welds have stood up.	Undetermined.	No.	1.00 to 1.50	
							Considering the subject.
1-h	System.	4	Welds stand up.	Undetermined.	No.	1.42	Tamp joints, replace worn anglebars and tighten bolts before welding.
1-h	Division.	5	Weld failures less than 5 %.	Undetermined.	No.	1.75	Welding gang also replaces frog bolts, etc.
1-h	Division.	3	Satisfactory.	3 to 5 years expected.	No.	1.20	Welding is confined to rail 5 years or more in track.
1-h	Sub-div.	8	Very satisfactory.	About 3 years.	No.		Select trackmen, usually foremen for welders. Gangs replace frog bolts, etc.
	Sub-div.	None now.	Not determined.	Not determined.	Not yet.	2.00	Question economy of welding.
1-h	System.	7	Generally satisfactory.	4 years.	No.	1.25	Renew worn anglebars and examine rail for defects when bars are changed.
	Division.	1	Very few weld failures.	About 3 years.	No.	2.08	
		None now.		None.	No.		Have not been able to develop any saving by welding.
1-h	Division.		No weld failures.	Not determined	No.	0.75 to 1.25	
	Division.	2	Good.	About 5 years.	No.	2.00	
							Just starting work. Have no data to furnish.
1 h	Division.	4	Very good.	Possibly 30 %.	No.	1.69	Welding gangs work mostly on frogs and switches.
2-h	System.	2	Good.	Approx. 2 years.	No.	1.56	Work done in 1924.
	Division.		Good.	No data.	No.	0.90 to 2.00	
1-h	Sub-div.		Less than 1 % weld failures.	2 years main line.	No.	1.89 to 2.04	Worn anglebars are changed before welding.
	System.	1	Good.	Possibly 5 years.	No.	1.70	
1-h	Division.	21	Satisfactory.	2 to 5 years.	No.	1.75	Joints are tamped a few days in advance of welding.
	Division.	12	Satisfactory.	2 to 3 years.	No.		Tamp joint and change worn anglebars before welding. Change rail where cost of welding exceeds $2.50 per joint.
	Division.	Varies.	Very good.	Undetermined.	No.	2.00	Have found it necessary to weld only a few rails.
	System.	3	O. K.	30 %.	No.	2.08	Rail laid prior to 1910 not welded.

Data from various roa

NAME OF ROAD.	Mileage.	Are joints welded?	How many years?	Method used.	Number of joints welded.	How are joints selected?	Is work done out of face?	Minimum amount of batter welded (in inches).
Missouri, Kansas & Texas	3 188	Yes.	4	Oxy-acet.	15 000	Inspection.	No.	1/32
Nashville, Chattanooga & St. Louis	1 260	Yes.	9 months.	Oxy acet.	2 858 to April.	Judgment of welder.	No.	3/64
New York Central	5 710	No.						
Northern Pacific	6 649	Yes.	2	Oxy-acet.	700	Inspection.		
(Western Road)	3 300	Yes.	3	Oxy-acet.	25 000	Inspection.	No.	1/8
Pere Marquette	2 263	Not now.		Oxy-acet.	2 008			
St. Louis & San Francisco	4 902	Yes.		Oxy-acet.	6 977			
St. Louis South Western	1 777	No.						
Seabord Air Line	3 929	Yes.		Oxy-acet.				
Southern	8 111	No.						
Southern Pacific (Pacific System)	8 758	Yes.	8	Oxy-acet. and elec.	329 583	Inspection.		
Southern Pacific (Louisiana & Texas)	4 510	Yes.	2	Oxy-acet.	6 500	Inspection.	No.	
Union Pacific Railroad	3 691	Yes.	7	Oxy-acet.	226 435	Inspection.	Yes.	1/16
(Union Pacific System)					(965 553)			
Wabash	2 522	No.						
Western Pacific	1 042	Yes.	3	Oxy-acet. and elec.	20 793	Inspection.	No.	1/16

the cost for welds 6 inches long averages $1.20.

The Atchison Topeka & Santa Fe built up 120 000 joints in 1925 at an average cost of $1.26. The cost on the Union Pacific, where a total of 226 435 joints were built up from 1921 to 1925, inclusive, has ranged between $1.00 and $1.20, while the average cost on the Illinois Central is $1.33, on the Great Northern $1.75 and on the Chicago, Burlington & Quincy $1.25. The Chicago, Rock Island & Pacific, which does a large amount of welding on frogs and crossings but which has not gone extensively into the practice of welding rail, reports that its costs for welding rail ends ranges between $0.75 and $1.25 ordinarily with an average of about $1, but that in exceptional cases the costs have run as high as $2.88 per joint. It states that the cost of welding in the winter is higher than that done in the summer and this statement is corroborated by the Union Pacific, the reason being that more oxygen and acetylene are required to bring the rail to fusing heat in cold weather, although the quality of the welding done in the winter is equal to that done during other seasons.

Results obtained by welding.

All of the roads engaged in welding joints report that the results are satisfactory, both in the improvement in the riding qualities of the track and in the lengthening of the life of the rail. Few

velding battered joints. *(Continued.)*

Organisation.			Results of work.	Increase in life of rail.	Any evidence of injury to rail?	Cost per joint including labor and material (in dollars).	*Remarks.*
(w = welder\ h = helper).	System or division.	Number of gangs.					
w, 1-h		t	Satisfactory.	3 to 4 years	No.	1.10 to 1.60	
w, 1 h	Division.	3	Satisfactory in most cases.	Not determined.	No.		Weld failures that have occurred have been on very soft rail.
w, 1-h pprox.	Division.		No apparent failures.	No data.	No.	1.00 to 1.50	Very little work has been done on rail.
	Division.	6	Practically no failures.	Not determined.	No.	1.96	Saves maintenance cost and provides better riding qualities.
			Fairly good.			2.35	Experimented in 1922 and 1923.
			Very satisfactory to date.	No data.	No.	1.15	Doing little at present. Work was done in 1923 and 1924.
							Have done too little to furnish data.
							Have experimented and are considering.
	Division.		Very satisfactory.	3 years.	No.	1 20	Using oxy-acetylene now principally but building some electric machines.
w, 1-h		3	Satisfactory.	No data.	No.	1.00	Gangs work principally on frogs and switches, worn joints are replaced before welding.
w, 1-h } w, 3-h }			Less than 5 % weld failures.	2 to 4 years.	No	1.00 to 1.20	Joints are tamped and worn angle-bars replaced before welding.
							Considering the subject.
			No weld failures.	No data.	No.	1.55	All welding now being done by electricity.

failures of welds are reported where the method has been in use for some time, most of the failures occurring when the practice was being inaugurated, due usually to inexperience. The Central of Georgia reports that the failures of welds have not been over 5 % and the Union Pacific reports less than 5 % of failures. The Nashville Chattanooga & St. Louis whose chief engineer, Hunter Mac Donald, has made exhaustive studies on the battering of rail joints, reports that the building up of such joints by welding was inaugurated on that road in January 1926 since which time a total of 2 858 joints have been welded with satisfactory results in most cases, and the weld failures that have occurred were chiefly on very soft rail. The Chicago Burlington & Quincy, which welded 95 000 joints from 1922 to 1925, inclusive, and whose program for 1926 covers 75 000 joints, reports that the results have been satisfactory.

The increase in the life of rail on which welding has been done varies, of course, with traffic conditions but on the roads where the practice is in extensive use a marked increase in life has been noted. The Atchison, Topeka & Santa Fe reports that the life of the rail is increased by about 25 % while the Minneapolis, St. Paul & Sault Ste. Marie reports 30 %. A western road which has welded 70 000 joints reports an increase in the life of the rail of five years, due to welding; the St. Louis-San Francisco reports four to six years, the

Chicago, Burlington & Quincy an average of four years; the Missouri-Kansas-Texas three to four years, the Delaware & Hudson possibly four years, the Southern Pacific (Pacific System), the Illinois Central, the Chicago & Eastern Illinois, and the Chicago Great Western, three years; the Great Northern, two to five years and the Union Pacific, two to four years. Other roads furnished no data as to this or have been welding too short a time to determine the increase in the life of the rail. The Baltimore & Ohio, which has been welding only a year, reports that while it cannot determine the increase in the life of the rail, the higher standard of joint maintenance is very noticeable.

Organization for the work

The organization for the work usually contemplates one or more welding gangs consisting of one or two welders and an apprentice or laborer, or some multiple of this crew. It was formerly the practice to assign one apprentice or helper to each welder, but in most cases it has been found that one helper is sufficient to serve two welders with a consequent reduction in cost. The welders and helpers are preferably selected from men who have had experience in general track work and on some roads, notably the Central of Georgia and the Chicago and Eastern Illinois, the welding gangs replace worn frog bolts and do similar work in addition to their welding, the latter road selecting track men, usually foremen, for this work. On roads where the building up of rail joints is carried on as the primary purpose of the gangs, they also build up frogs and crossings as they come to them. Other roads, such as the Delaware & Hudson, the Lehigh Valley and the Northern Pacific maintain welding gangs primarily for frog and crossing work and use them incidentally to build up the rail joints, the Atlantic Coast Line and the Lehigh Valley confining their welding to rails with chipped ends.

When the gangs are working principally on frogs and crossings in track, they are furnished with motor cars for transporting themselves and the gas tanks over the road, and with outfit cars for living quarters when on the road. When their work also includes considerable work on rail joints they are usually provided also with specially designed dollies or buggies for moving the gas tanks from joint to joint. One such carrier is designed like a hand truck so that it can be used for trucking the tanks on ordinarily even surfaces, and is supplied with an extra pair of double flanged wheels set transversely on the body to allow them to rest on one rail of the track, a hinged outrigger with a roller on its end resting on the other track rail. This arrangement permits the gas tanks to be moved easily along the track and permits the ready removal of the device when necessary to clear trains.

Practice varies as to the assignment of gangs, some roads assigning them regularly to certain operating divisions, while others move them from division to division as their services are needed. Some roads, especially those in northern regions, among which may be mentioned the Union Pacific and the Minneapolis, St. Paul & Sault Ste. Marie, work the gangs on the track during the open seasons and in the winter assign to them the work of buiding up frogs and crossings which have been removed from track on account of wear, thus putting them in condition for further service. On a number of roads preliminary work preparatory to welding is done in the way of tamping up the joint ties, adjusting expansion, applying anti-creepers where needed, and replacing worn angle bars. Among the roads following this practice are the Chicago Burlington & Quincy, the Erie, the Great Northern, the Illinois Central, the Southern Pacific,

the Union Pacific, and the Buffalo Rochester & Pittsburgh. E. F. Robinson, chief engineer of the latter road states that it is their opinion that the work of reconditioning rail ends by welding is an unwarranted and useless expense unless the joints are first put in good condition, including replacing muddy ballast under the joints with clean ballast, surfacing and retamping the joints, renewing bent, worn or cracked angle bars or joints and tightening bolts.

Fig. 1. — Welding with a special tank carrier.

Most roads which are welding use 1/16 inch as the minimum amount of batter to be welded and perform the work out of face, at least to the extent of buiding up in any particular stretch of rail all joints with chipped ends or which have more than the predetermined amount of batter in any given stretch of rail. However this practice is not universal for the Central of Georgia reports that it does spot welding almost exclusively and that the number of joints to be welded does not ordinarily run over 25 or 30 to the mile while the Minneapolis, St. Paul & Sault Ste. Marie states that it is shaping its work along lines which will provide for building up all battered joints out of face and dispense with the necessity of covering the same territory so often.

In selecting the joints to be built up it is the common practice to do this by an inspection carried on by the division engineer, roadmaster or supervisor, using a straight edge and taper gage to measure the amount of batter. On the Central of Georgia and the Chicago Burlington & Quincy the length of the weld is marked for the guidance of the welder at the time the inspection is made.

Work on specific roads

Illustrative of the methods pursued on the roads which have gone into this matter on an extensive scale may be cited the organization on the Southern Pacific where 103 539 joints were built up in 1925, and where the total number of joints welded amounted to 329 583 to the end of April of last year. On this road each operating division has a gang of welders consisting of from 2 to 14 men under the general supervision of a superintendent of welding. Where the gang contains more than one welder, a lead welder is designated to take charge of the outfit. The joints to be built up are selected by the welder who has been instructed by the division engineer and the roadmaster as to the location of the work. Where welding is

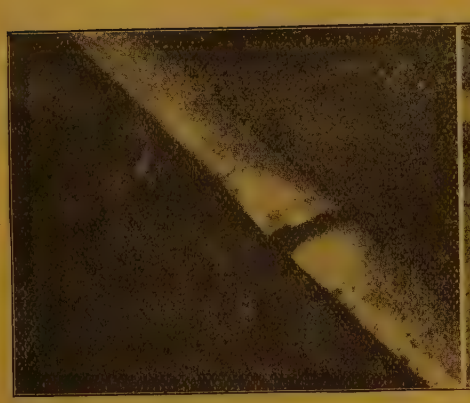


Fig. 2. — Joint before welding.

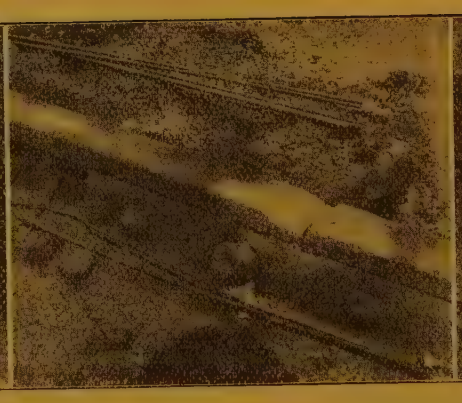


Fig. 3. — Joint fused for welding.

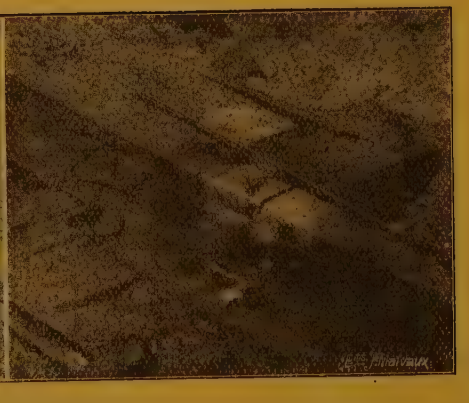


Fig. 4. — The finished weld.

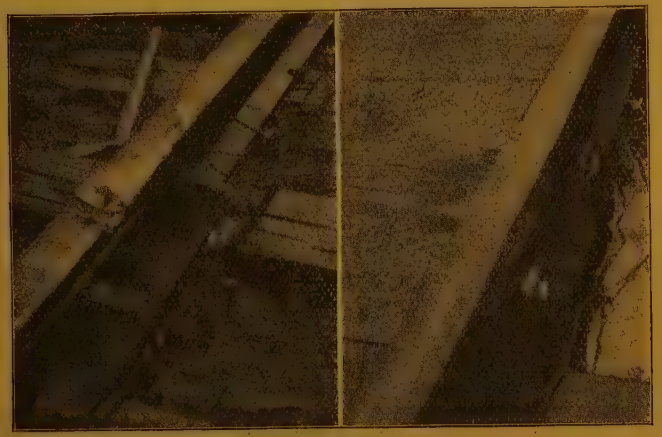


Fig. 5.
A battered joint before welding.

Fig. 6.
The same joint after welding.

Fig. 7.
Welding gang working on main line rail.

to be done the track is worked over by the section forces who close up the expansion, tamp the joint ties, renew worn angle-bars and apply anti-creepers in advance of the welding operations. In determining the joints to be built up a straight edge is laid longitudinally on the rails across the joint and all joints showing a deflection from the plane of the tops of the rails are built up. A number of welds have been in service six years and it is estimated that the life of the rail in its first cycle of use is increased about three years.

The Atchison, Topeka & Santa Fe built up 120 000 joints in 1925. On this road, welding gangs, usually consisting of two welders and a helper, are assigned to each assistant general manager's territory, there being a total of 40 gangs on the system at the present time. When any stretch of track shows battered rail ends a gang is placed on it, working over it out of face and building up all joints showing a depression of more than 1/16 inch. A recent investigation showed that the joints built up are proving very satisfactory and it is estimated that the life of the rail in its first position is increased 25 %.

On the Union Pacific proper 226 436 joints were built up from 1921 to 1925, inclusive, there being no record available of the number built up prior to 1921. On this road the division engineer selects the joints to be welded, which are restored to the exact line of the plane of the tops of the adjacent rails, all joints showing batter of 1/16 inch or more being built up.

In unsettled country it is found practical to assign four to six welders, with two to three helpers to a gang, furnishing them with camp cars for living quarters. In settled country, with greater traffic density, one welder and one helper usually constitute a gang, which is furnished with a camp car. The welding gangs are a part of the division force and are under the general supervision of the general roadmaster who directs their movements from one roadmaster's district to another, the gangs being under the direct supervision of the roadmaster of the district on which they are working. Over 95 % of the welds have stood up under traffic and there has been no injury to the rail since the adoption of a special welding steel in 1921. It is expected to increase the life of the rail from two to four years by this method.

The Great Northern began building up rails in 1921, and to date has welded 210 000 joints and in addition has repaired 15 000 frogs and approximately 5 000 switches in track by this method. A welding gang of two welders and one helper is assigned to each division, and a total of 21 gangs are now used. The work to be done is determined upon after special inspection and is confined to joints with a batter of 1/16 inch or more and to those with chipped ends. The results as a whole have been satisfactory although there were a few partial failures of the welds when the work was started. The life of the rail is increased from two to five years.

The Chicago, Burlington & Quincy began welding experimentally in 1922, when 1 500 joints were built up, and continued the work in 1923, when 3 500 joints were welded. The experiments proving successful, the work was put into regular operation in 1924, 30 000 joints being built up in that year and 60 000 in 1925, while the program for 1926 contemplates the welding of 75 000 joints. On this road the standard gang consists of a head welder, three welders and two helpers, although at times five welders and three helpers are used in a gang. Seven gangs are employed in this work and are moved over the system as needed, remaining on a division only long enough to do the work authorized and working under the supervision of

the roadmaster, the district engineer having general supervision of the gangs while they are on his district.

When the rail in a stretch of track begins to show noticeable batter or chipped ends an inspection is made by the district engineer, accompanied by the division superintendent and the roadmaster. As a general rule welding is not decided on unless 50 % of the joints show approximately 1/16 inch batter or are chipped. The general condition of the rail, the amount of traffic and other pertinent factors are taken into account, a separate study being made of each stretch of track inspected. No evidence has been found of any injury to the rail due to welding and, as has been said, this subject has had special attention during the past year. With the exception of some few failures in the early stages of the work the welds have stood up satisfactorily under traffic and the life of the rail has been increased about four years.

The Illinois Central started building up joints by welding in 1921, and has continued the practice every year since that time with satisfactory results, 125 000 joints having been welded during that period. The joints are selected by the track supervisor with the rule that where the cost of building up a joint will exceed $2.50 the rails is to be changed out instead. The joints are tamped and worn angle bars are replaced in advance of the welding. This road now has 12 outfits operating on divisions, each welder building up about 10 joints per day. No injury to the rail has been found and the life of the rail is increased from two to three years.

Not all roads have continued welding.

Some roads which have done welding with good results are not doing the work except in special cases but anticipate that they may find it desirable to do so later on. Thus the Northern Pacific, which maintains a welding outfit consisting of a welder, apprentice and helper on each division, has only built up 700 rail joints, of which 640 were on a branch line relaid with rail having battered joints, where the work was done to improve the riding qualities. This road states that a large proportion of its main line rail is 90 lb., which for various reasons it is not desired to maintain in the main line beyond its normal life, since the demand for good relay rail for branch lines and new construction often necessitates the removal of this rail from main lines before it would be released otherwise. When the 100 lb. and 130 lb. rail, which is now being laid in main track, develops battered joints it is thought likely that the practice of building up the joints will be adopted. Similarly, the Chicago, Rock Island & Pacific feels that while there is merit in building up battered rail ends in certain places and under certain conditions, such as where the weight of rail in the track is the same as it is proposed to maintain there and where the expense is warranted in securing as great a life as possible out of the rail before it is renewed. On the other hand it believes there is no economy in attempting to prolong the life in the first cycle of service of rail of lighter section than it is expected to maintain in the track, other than to build up occasional battered joints.

The Chicago, Milwaukee & St. Paul has done some experimental work during the past three or four years, building up the joints on four or five miles of track by the oxy-acetylene process, but states that it has not been able to develop sufficient savings by welding rail to justify the expense. It has two system outfits welding crossings and frogs. On this road when the rails and fishing surfaces are worn and the receiving rails are pounded down but not badly battered it is the practice to renew the joint bars and at

the same time to adjust the expansion and gage the track. The Pere Marquette also experimented with welding on its Detroit division in the fall of 1922 and the spring of 1923, building up 2 008 joints at an average cost of $2.35 per joint, but has done no welding since that time.

The Chicago & North Western has built up isolated joints for five years and carried on more extensive operations for two years, a total of 30 000 joints having been welded at an average cost of about $2. It is not now doing any of this work extensively as it is not satisfied that the life of the rail is increased sufficiently to justify the expense of building up all joints out of face, rather than confining operations to exceptional joints or those battered 1/16 inch or more. The Denver & Rio Grande Western reports good results from 6 000 joints built up in 1924, at an average cost of $1.56, but has not continued the work.

[625.143.4]

Track joints and their maintenance. (1)

Figs. 1 and 2, p. 222.

(From *Railway Engineering and Maintenance.*)

The purpose of a track joint is to hold the ends of two adjoining rails together and in line and surface. To do this when there is no load upon the rails is of course a simple matter, but when the rails are loaded with a passing train, the requirements imposed upon the joints are not so simple. Take the case of a modern locomotive with wheel loads of between 30 000 and 35 000 lb., passing over the track and the burden placed upon the rail joint is of great consequence.

Unfortunately many people, and this applies particularly to the vast majority of would-be inventors of rail joints, have the idea that all that is required of a rail joint is to hold the load up. This, however, is far from being the case, for the laws of motion, as we find in the study of physics show « that for a body at rest to remain at rest it must either have no force acting upon it, or it must have equal and opposite forces acting upon it ». Therefore, if our railway track rails, with their joints, are to stay in place, for every wheel load bearing downward upon them, there must be an equal tie support bearing upward against them. This tie support is just as much a force as the weight of the locomotive or car on top of the rail, and it acts in the opposite direction from the wheel load action.

The more flexible the rails the fewer ties there will be helping to hold up the load, consequently a greater force will be exerted by each tie.

Figure 1 is prepared with arrows above the rail representing the wheel loads of a locomotive acting downward on the rail and arrows below the rail representing the forces, or loads of the ties acting upward on the rail. Figure 2 is the same chart turned upside down to make it easier to realize that the forces of the ties' resistance constitute a load on the rail just the same in amount, but acting

(1) Committee report presented at the Roadmasters Convene, Chicago, 21-23 September 1926.

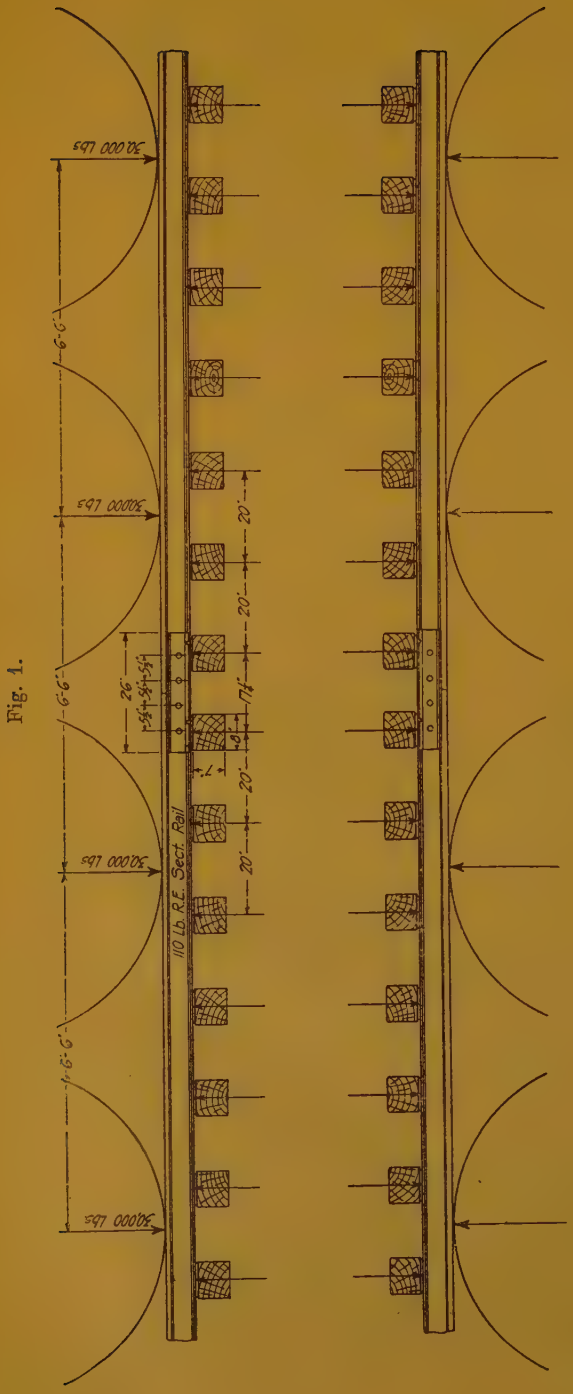


Fig. 1.

Fig. 2.

in the opposite direction from the load of the wheels.

This shows that with the locomotive wheels spaced as indicated in the figures the forces of four ties are acting upon the joint between the opposing forces, or supports, and consequently exerting as much force upward on the joint as is exerted downward by the wheel load when directly over the joint, and with perhaps greater lever arms. This should make it clear that the upward force acting upon a rail joint, due to the ties, is as great if not greater than the downward force of the wheel load on the joint.

The design of a joint.

Because of the forces acting upon the joint as described above, it is necessary to make an efficient rail joint, that it have sufficient strength in both the top and bottom parts of the joint to prevent breaking, due to the stresses in either direction. The joint must also have sufficient bearing on both the underside of the head of the rail and the upper side of the base of the rail to transmit the stresses properly between the rail and the joints without undue wear.

If the joint bars are made to fit on the top and bottom *of the base* of the rail, with little or no bearing against the head of the rail the entire load on one rail must be transmitted to the next rail through the bases of the rails only. This applies to the upward acting forces the same as it does to the downward acting forces, and represents a complete change in the location of the neutral axis of the supporting members through the joint from where it exists in the rail away from the joint. Such joints are quite likely to result in many base failures of the rails, because the rails are not designed to handle the load in such a manner.

Joints which fit between the head and the base of the rail should be so made as

to leave enough clearance between the joint bar and the web of the rail to provide for taking up the wear of the contact faces by tightening up the bolts, thus drawing the joints into proper contact gain. Joint bars should be so designed that they will keep the tops, or faces of adjoining rails as near the same level as possible.

The use of any type of joint which has a base plate or a supporting section projects underneath the base of the rail, brings all the difference in the height of the two adjoining rails to the top, resulting in a tendency for the top of the higher rail to flow over onto the lower rail, or into the opening between the rails and thus become the cause of a chipped or battered end rail. Also, the joints which have a supporting base are generally used without tie plates, on the mistaken idea that such base plates of the joints take the place of tie plates.

The object of a tie plate is to protect the tie from being cut by the rail, and to be effective, the tie plate should remain in constant contact with the tie without any movement for it is the movement which produces the cutting. For example, a file drawn across a piece of metal with only a small pressure will cut away the metal, while the same file if held still will bear probably a thousand times the load and cause no abrasion or cutting away of the support. The base plate of a joint, to be of any value to the joint, must be attached to the rail and move when the rail moves; to be a tie plate it would have to be free from the rail and remain with the tie without movement. Obviously it cannot be both at the same time.

The use of a joint which fits between the head and the base of the rail only and does not have any connecting portion under the rail, results in lining up the two rails on the top line of the joint bar, and only the difference in the thickness, or depth, of the rail heads comes to the top, thus making much less difference in the level of the tops of the rails.

The most efficient rail joint would seem to be one which :

1. Presents a good bearing surface to the underside of the head, and to the upper side of the base of the rail.
2. Has sufficient clearance from the web of the rail to permit the continued fit of the joint, in the fishing space of the rail, until a considerable amount of wear has taken place.
3. Has sufficient metal properly distributed above and below the neutral axis to take care of the forces acting upward as well as of those acting downward.
4. Produces the greatest strength in proportion to the amount of metal used.

The length of track joints.

In addition to the design of the rail joint, there is a question as to the most effective length of the joint and the number of bolts which will best carry the forces acting upon it.

The study of the rail and joint and of the forces acting upon them, as shown in figure 1, indicates that a joint long enough to cover three ties, with the ties so spaced that one of them is directly under the rail ends, increases the number of ties which are bearing the load directly with a consequent decrease in the tie forces acting against the rail at each tie. It also indicates a better proportioning of lever arms, but an analysis of the forces and lever arms, etc., of various arrangements of ties at joints would be too long a problem for consideration here. Experience gained from the actual use of joint bars long enough to span three ties and fastened with six bolts, indicates that they give results superior to the shorter joints fastened with four bolts, but whether they have sufficient advantage over the shorter bars to justify their greater cost, is not proven definitely.

As between a four bolt joint with ties spaced to a uniformly suspended joint,

and a four bolt joint laid « hit or miss », a long and detailed study of lever arms and bearing points of the forces acting would have to be made to determine their relative merit, and even then it is doubtful if a definite decision could be reached without keeping careful cost records of installation and maintenance throughout the life of the rail and the joints in track.

A study throughout the life of the rail, of the maintenance costs and the length of the life of rail under conditions as nearly identical as possible, except with different length joints, and of spaced ties, and of « hit or miss » laying of rail would be required to reach a decision as to the superior length of joints and manner of laying.

It is more than probable that a rail joint long enough to bear upon three ties, if the ties are spaced, is the better joint for use where rail is laid « hit or miss », as the longer joints are more certain to provide a good support for the rail ends, no matter where they may be with reference to the ties.

Experience with « hit or miss » laid rail is also indicating that joints can be maintained better by depending upon rail anchors to prevent the rail from creeping, and the eliminating of slot spiking of the joints. The slot spiking of the joints results in more or less, usually more, damage to the joint ties with consequent greater difficulty in joint maintenance. It is also good practice to provide for the wave motion of the rails to take place without disturbing the ties by leaving the spikes from 1/16 to 1/8 inch above the base of the rail.

Ties of uniform size, and of as near an average of all the ties used, should be selected for use as joint ties. If rail anchors are used opposite the joints, care should be taken to so place the tie plates that the anchors will not make contact with the plates, as rail anchors bearing against any tie plate thraw the anchorage against the spike and produce all of the bad effects of slot spiking.

The kind of bolts and springs.

Following the selection of a type of joint comes the question of the kind of bolts and kind of spring washers or spring plates, if either are to be used.

Prior to 1912 loose bolts in rail joints where a common occurrence and called for a large amount of maintenance work to keep them tight. The idea was then quite generally held that nut locks were necessary on track bolts to prevent the nuts from backing off, or unscrewing. From an experiment made for another purpose it was discovered that most loose joints were due to the stretch and wear of the low carbon steel or iron bolts then generally used, and that the nuts on track bolts very rarely backed up, or unscrewed.

Following the discovery of the causes of loose joints, the alloy steel bolts were offered for track use, followed soon after by heat-treated high carbon steel bolts. Prior to the introduction of these high strength bolts it was impossible to bolt up a joint too tightly because the bolts would stretch before that condition was reached.

Joints should not be bolted too tightly.

The much greater strength of the improved bolts has resulted in many rail joints being bolted up so tightly that the rail cannot slip through them to take care of the expansion and contraction of the steel due to changes in temperature. This condition results in kinky track in hot weather and occasionally in the shearing off of the two bolts in one end of a joint, here and there, in severely cold weather. On this account it is important that some form of spring washer or spring plate be used on joint bolts. Some roads are reporting good success with each type of springs but it is possible to get joints bolted too tightly, even where springs are used.

Tests and experiments are under way to determine how tightly rail joints

should be bolted and how to keep them at the desired tension after they are installed. It is quite generally conceded that heat-treated high carbon steel bolts with rolled threads should be used for rail joints and that some form of spring is desirable to maintain uniform pressure on the joints.

The installation of joints.

An important factor in the efficiency of rail joints and in the cost of their maintenance is the manner of their application to the rails and the proper laying of the rails. The expansion and contraction of steel rails due to changes of temperature are very positive phenomena of nature and cannot be prevented or abolished. Consequently when laying rails the temperature of the rail itself should be determined at frequent intervals and the proper amount of space to take care of all expansion which may occur should be provided by use of spacing shims.

It is usually necessary to remove the shims before the joints are fully bolted up. However, the dipping of the shim in heavy oil or graphite paint before its use will usually facilitate its removal. Care must be taken to remove all expansion shims before leaving the rail-laying job. The rails should be anchored at once to preserve the expansion space provided for each rail, instead of permitting it to bunch up, resulting in tight joints at some places and wide spaces at others.

The joint bars should be clean and should be given a coat of oil all over and preferably a coating of graphite on the bearing faces. The oiling of the underside of the head and the upper side of the base of the rail, for the length of the joint bars, is also good practice. The joints should then be applied and bolted up as tightly as they can be without making them so tight as to prevent the slip of the rails due to expansion and contraction.

In order to insure the rails lining up correctly, that is to avoid lipped joints, the two bolts nearest to the rail ends should be tightened a little ahead of the remaining bolts.

If the bolts farthest from the rail ends are tightened first it results in the ends of the joint bars being bowed in somewhat and clamped into the fishing space of the rails. This occasionally results in the bars being prevented from slipping at the ends and leaves their centers bowed outward with consequent failure to line up the rail ends properly.

On rail-laying jobs the nuts on track bolts should be run up by power-driven wrenches, and the final tightening should be done with a hand wrench not over 36 inches in length, except where a wrench is used which is equipped with an indicator device which shows the tension on the bolt at every stage of the tightening up of the nut. Such a wrench has recently been invented and it should prove of great benefit in the proper application and maintenance of rail joints.

The maintenance of joints.

The maintenance of joints, if restricted to the position of the joint bars only, would be a short story, but maintenance of joints is usually understood as embracing the fit and condition of the joint bars, the condition and tightness of the bolts, the condition of the rail ends and the line and surface of the track at and near the joint.

The maintenance of the joint bars should consist in seeing that all cracked or broken joints are replaced promptly, keeping the joints bolted tightly enough to transmit the stresses properly from each rail to the other and making sure that the joints are not bolted too tightly to permit of the slip of the rail to take care of the expansion or contraction of

the rails due to changes in temperature. This may require the loosening of the bolts on some joints that are « frozen » (that is, clamped too tightly to allow of slip), and sometimes prying or jarring them loose from the rail, then to tighten them again to the proper extent, the replacement of all defective or worn bolts and the tightening of any bolts which may be found loose.

Track men should not get the idea that every bolt must necessarily be tightened some when going over their track tightening bolts. Some bolts may be tight enough. Care should be taken to avoid the use of wrenches which are too long, as extra long wrenches will result in some joints being bolted too tightly, where high strength bolts are used.

The stretching of a bolt is a damage to the bolt for it has less strength after it begins to stretch than it had before.

The condition of the rail ends is very important, and foremen should be instructed to have any metal which rolls out from the end of the rail sawed or chipped off to prevent its acting as a wedge when the rails run together, and causing a chip to be split off the end of the adjoining rail. When rail ends become battered or chipped to such an extent as to cause pounding of the joint, they should be repaired by welding. Section foremen should be instructed to keep watch of joints which are battered or chipped enough to cause extra work to be done to keep them surfaced up, and to notify the roadmaster at regular intervals of the location of joints needing the attention of the welding gang.

All joints should be watched for alinement and if found to be out of line to a greater extent in hot weather than in cool weather, steps should be taken to determine if the rails are laid too tightly or whether the joints are bolted so tightly that the rails cannot slip through them, and utilize the spaces left for expansion. If the latter is found to be the case the bolts and joint bars should be loosened enough, at all points showing expansion spaces, to permit the slip to take place. If the rails are found to be laid too tightly the only remedy is to remove a rail at proper intervals and replace it with a shorter one, then to even up the expansion by the space thus provided.

When joints get out of surface to an unusual extent the cause is apt to be poorly drained roadbed or chipped or battered rail ends. If due to wet roadbed the ballast should be cleaned and proper means of drainage provided. If the rail ends are chipped or battered the welders should be called to repair them.

[621 .33 (.42) & 625 .4 (.42)]

The new Morden extension and Kennington loop lines.

Figs. 1 to 20, pp. 228 to 245.

(From *The Railway Engineer*.)

The recent opening of the Morden extension and the Kennington loop lines constituted the concluding instalment of a comprehensive scheme of improvement carried out on the City & South London Railway, and the Hampstead section of

the London Electric Railway. The works previously executed, in 1922-1924, comprised the reconstruction of the first-named line, in accordance with modern « Underground » standards, the establishment of a physical connection with the Hampstead Tube at Camden Town, and the extension of the Golder's Green branch of the latter railway to Edgware *via* Hendon.

The new lines consist of an extension of the City & South London Railway, about 5 1/2 miles in length, from Clapham Common through Balham, Tooting, Merton and South Wimbledon to Morden, and a connecting line of the London Electric Railway, some 2 miles long, from Charing Cross to Kennington. At the latter point a second physical connection has been made between the two systems, which now assume the form of a circular railway through the City and West End, throwing off branches to Edgware in the north-west and Morden in the south-west.

The Parliamentary Acts for the Morden extension and Kennington loop were passed in August, 1923. Construction was commenced early in the following year, and the lines were opened for traffic on 13 September 1926.

Engineering details.

From Clapham Common to Dorset Road at Merton — a distance of some five miles — the extension is of the usual form of twin shield-driven, iron-lined tunnels, of standard tube design. The average depth beneath the surface is 40 feet, the tunnels rising at Dorset Road to within a few feet of the surface. The running tunnels are 11 ft. 8 1/4 in. in diameter, increased at the station platform tunnels to 21 ft. 2 1/2 in. Between the stations the running tunnels are an average of 5 feet apart; at the stations they diverge to allow for the escalator shafts to come between them. The running tunnels rise and fall on the switch-back principle — a system applied wherever practicable on tube railways.

On leaving the stations each running tunnel has a declivity of 1 in 30 for about 300 feet, whilst on approaching the stations it has an acclivity of 1 in 60 for about 600 feet. Thus, although the tunnels are at the same level for a considerable distance between the stations, they rise and fall at different angles in the sections adjoining the stations. This arrangement promotes acceleration of the trains as they depart from the stations and retards speed as they approach the stations, thus making for economy in current consumption and relieving wear and tear on the brakes.

In constructing the line, the running tunnels were laid out in eight sections, five of which represented the distances between stations, with an average length of 3 000 feet. Between Tooting Broadway and Colliers Wood the tunnels were constructed in two shorter sections, in order to facilitate work at the former point, the use of compressed air being necessary here, owing to the ground being waterlogged. The eighth section was between South Wimbledon and Dorset Road. Certain sections were driven from north to south, others from south to north. At Tooting Broadway a one-road siding has been formed. Here, and at Balham and Trinity Road, where extensive diversions of gas and water mains were necessary, operations were of a protracted nature.

Tunnelling proceeded from service shafts sunk, in the majority of cases, at the station sites. Two types of excavating shields were used — the Greathead shield and the rotary excavator. The latter was used only for tunnelling through clay, when expeditious work was necessary, the appliance not being adapted to excavating a gravelly stratum. In all, 18 service shafts were sunk, and during the height of activities 12 ordinary-size shields and six extra large ones

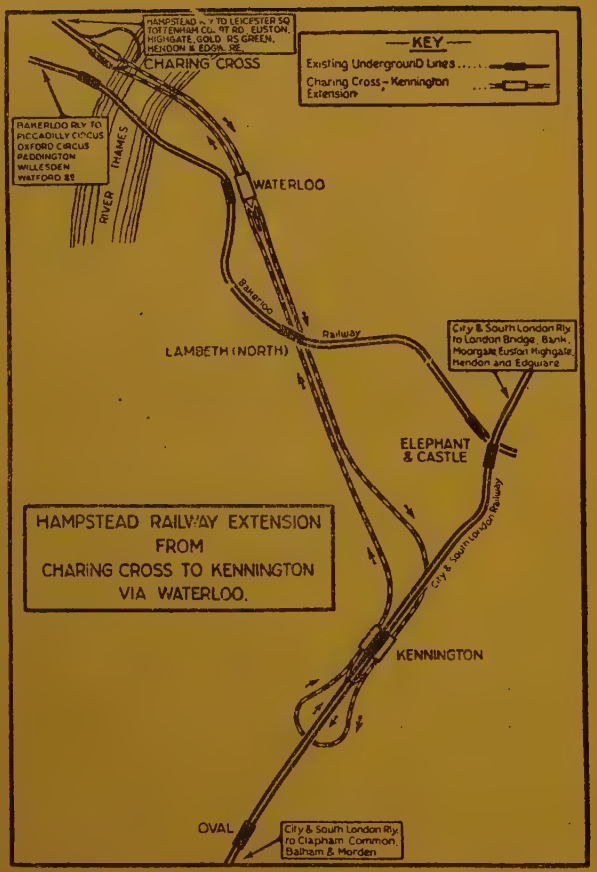


Fig. 1.
Map of new works between Charing Cross and Kennington.

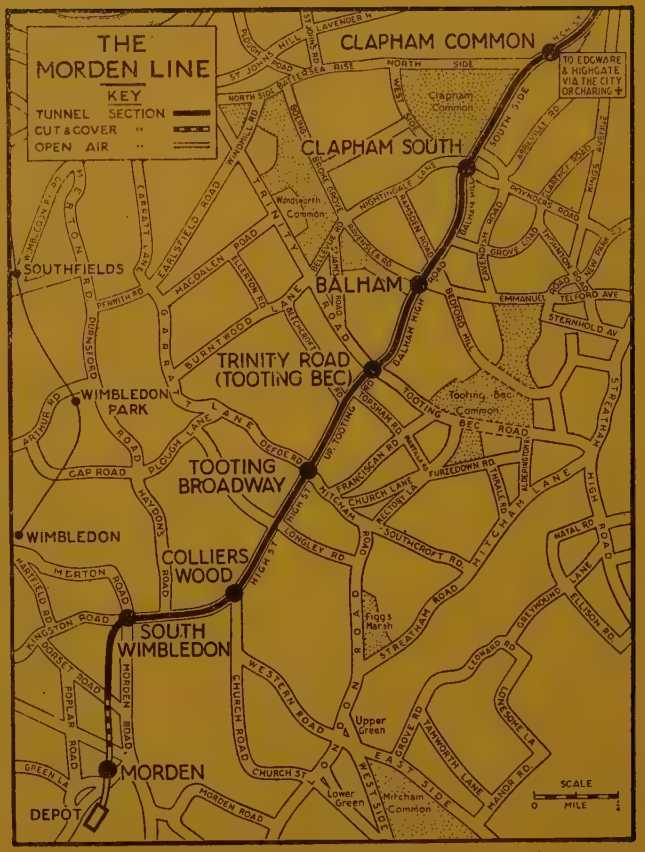


Fig. 2.
Map of Morden extension, showing roads, etc.

(for platform tunnels) were at work simultaneously at various parts of the line. Escalator shafts and passages at stations were driven by hand.

The shafts on the Morden extension were only 10 ft. 6 in. in diameter, whereas those used in constructing the older tube railways of London were from 16 feet to as much as 30 feet in diameter, and in them the lifts and emergency staircases of the stations were installed after the completion of the tunnelling. On the Morden line the stations have escalators; hence the temporary shafts formed here were, for reasons of economy, of small size.

Reinforced concrete tunnels.

The tunnels of this type at Merton are unique so far as the Tube railways of London are concerned. Their adoption was due to water-bearing stratum being discovered a few feet below the surface. In normal circumstances the line between Dorset Road and the Morden station would have taken the form of an open cutting the whole of the way. The continuation of the shield-bored tunnels was impracticable, owing to the shallowness of the site to be cut through. The concrete tunnels were constructed in sections, on the cut-and-cover principle, by a somewhat unusual method. Two parallel rows of steel piles were driven into the ground and the earth between them excavated, so that the piles formed the sides of a trench. Wood sheeting was then erected at each side, about 6 inches in front of the piles, the intervening space being filled with sand. The steel rod-work of the reinforcements was placed in position, and the concrete floor laid. The latter having set, two collapsible forms, or moulds — the patterns of the twin tunnels so to speak — were run forward alongside each other on trucks, and concrete was poured in, being well rammed and carefully packed about the reinforcements. When the concrete had set, the stays were withdrawn from the forms, and the latter were then moved forward and re-erected in the next section, which had meanwhile been prepared. The concrete roof was then laid, and this, too, having set, the piles were removed — to be used again in a section ahead — the surface of the ground being thus restored. The holes left by the piles were filled in by the sand already referred to, and the wood sheeting at the sides of the tunnels was left *in situ*. Finally, the inside of the twin tunnels was smoothed over by hand.

These concrete tunnels are 550 yards long and, allowing for the varying surface levels, they have a rise of about 12 feet. The entrance from the station cutting are faced with brick. At each end of the tunnels sumps have been formed to collect such water as may run down from the inclined cutting. Each sump has a pumping-house above it, to enable the water to be pumped from the sumps into a drain connected with the main sewer in the roadway outside.

The Kennington loop.

This link between the Hampstead Tube at Charing Cross and the City & South London Railway at Kennington is about two miles long, and is of standard shield-driven iron-lined tunnels throughout. Construction was carried out from shafts sunk at four points on the line of route. From Charing Cross the line begins its passage beneath the Thames with a fall of 1 in 30, which takes it well down below the bed of the river where it follows a course parallel to Hungerford Bridge. On approaching Kennington the twin tunnels diverge from each other, the « down » tunnel descending and passing under the City & South London Railway, and, curving to the south, it gradually rises besides that line, entering the station at practically the same level. Taking a shorter course, the « up » tunnel curves round into the station on the opposite side, the tunnels of

the City & South London Railway thus being between those of the loop.

Beyond the stations the tunnels of the new line run beside those of the City & South London Railway for a few yards and then, enlarging, throw off branches to make physical connections with the tracks of that line, afterwards diverging again. Descending at different gradients, they sweep round towards each other to form the head of the terminal loop, which is situated under the City & South London Railway, and extends as far south as the verge of Kennington Park. On the curving head of the loop the tunnels have a diameter of 12 ft. 6 in.

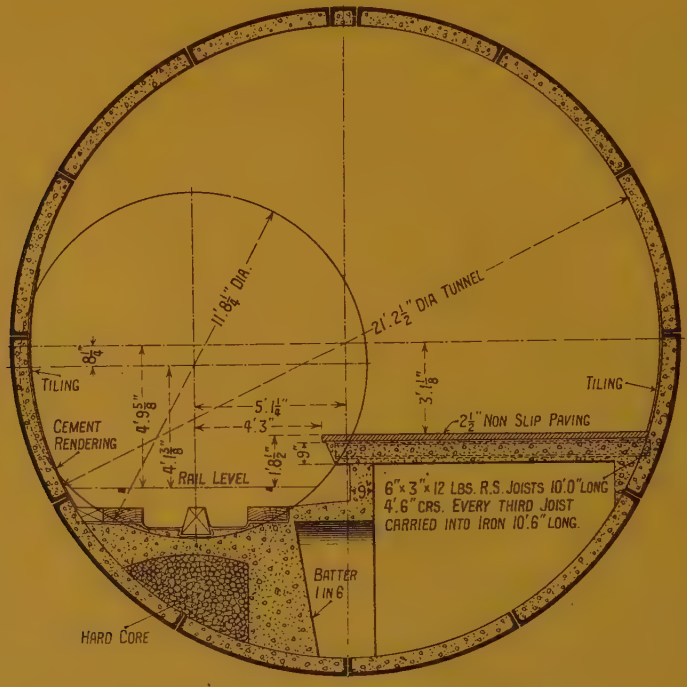


Fig. 3. — Cross section through tube at station.

In driving the « down » tunnel a stratum of hard rock, having a maximum thickness of 2 feet, was encountered below Kennington Park Road. This unusual feature in London geology had to be broken out by hand as the excavating for the shield proceeded. The loop at Kennington is comparable with the one that served as the terminal of the Hampstead line at Charing Cross, with the distinction that both the tunnels forming the neck of the Kennington loop pass through the station instead of only one.

Constructionnal difficulties.

The engineering difficulties entailed in the construction of the new lines were in places of a formidable character. At the points where operations were proceeding the loop tunnel was sealed with concrete filling, to prevent the compressed air escaping from the works; whilst at the precise places at which it was to be cut through by the new tunnels it was filled with rough brickwork, as a precaution against a weakening of the old

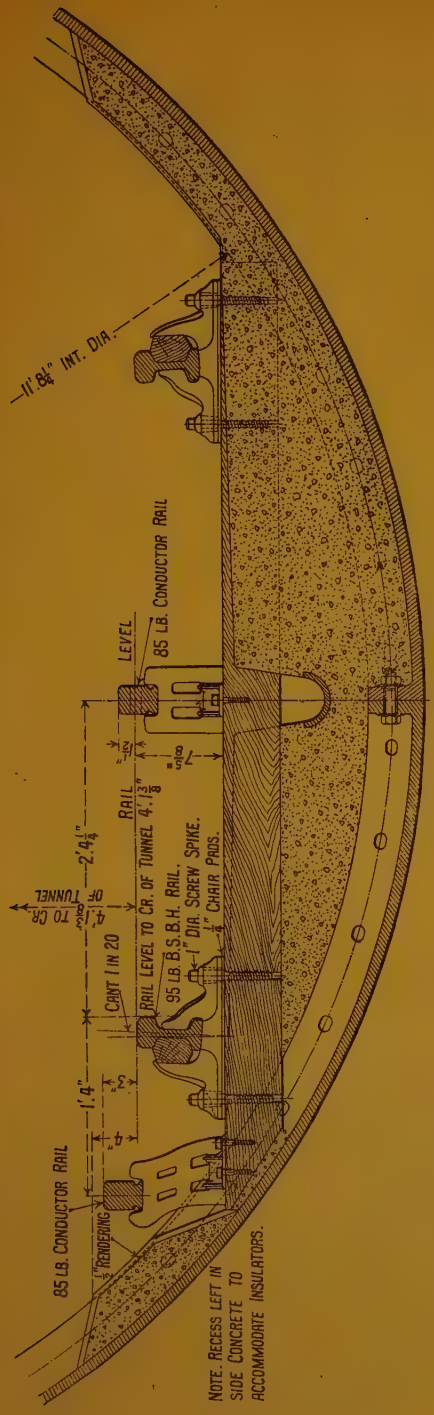


Fig. 4. — Cross section of lower portion of tunnel, showing arrangement of running and conductor rails, sleepers, etc.

tunnel, whilst the new ones were being driven through it.

The whole of Charing Cross Station is built in the old foreshore of the Thames, upon which the Victoria Embankment and its contiguous gardens are laid out. The ground here is water-logged, and the difficulties of driving the new south-bound platform tunnel of the Hampstead Tube through such treacherous ground were very great. As a precaution against a disturbance of work through a failure of electrical power, three independent supplies of electricity were made available during the course of construction.

The tunnels between Charing Cross and Waterloo were driven from the latter point. When work was proceeding under the river a factor that had to be considered was the fluctuating weight on the clay, which varied as the tide rose and fell. This necessitated adjustments of the compressed air from 10 lb. to 20 lb. per square inch, and *vice versa*. Towards the northern bank of the river, the cover of clay being less here, only half-ring lenghts of tunnelling were excavated at a time, instead of the usual full-ring lengths of 20 inches.

The installation of escalators at the new Waterloo station involved extensive underpinning of the piers of the arched viaduct carrying the main line station of the Southern Railway. The shaft containing them was driven down through a stratum of water-bearing gravel, the depth of water being 14 feet, protracted work in compressed air being necessitated. The north-bound platform tunnel had to be formed entirely by hand, instead of being shield-driven, in order not to interfere with tunnelling operations then in progress between Waterloo and Charing Cross, as compressed air was being supplied to the latter section of the works through a pipe passing through part of

the site of the platform tunnel in question. The excavating of the tunnel by hand obviated disturbance to this pipe.

In order that certain trains of the City & South London Railway may be reversed at Kennington for the return north, with-

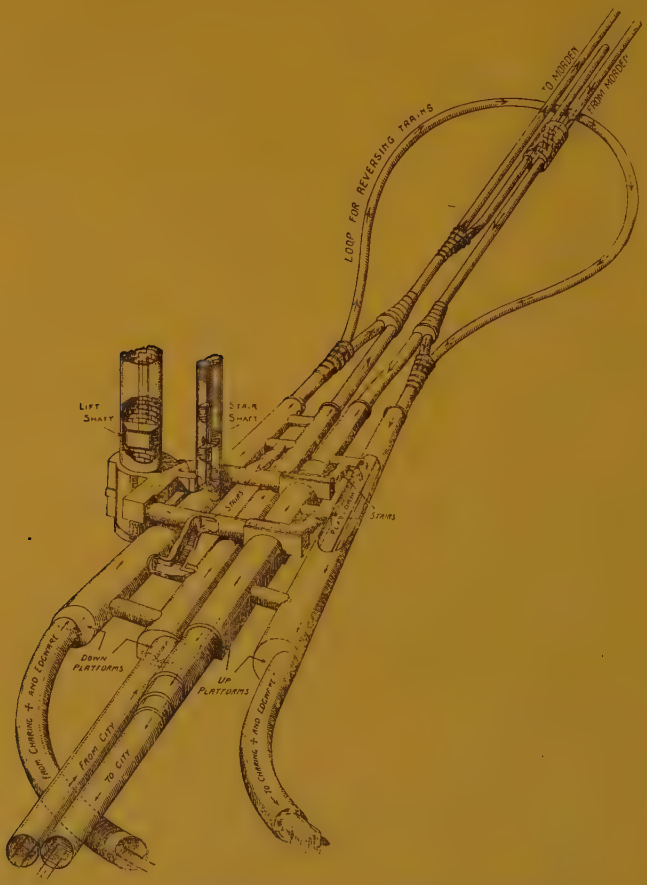


Fig. 5. — Perspective view of Kennington connection.

out deranging other services on this line, a siding has been constructed to the south of the station. It is capable of taking two full-length trains, which enter it from the « down » running tunnel and pass back from it into the « up » running tunnel.

An intricate problem.

The construction of this siding — carried out from two shafts sunk in Kennington Park Road — was a very interesting example of tube engineering. At Kennington there is a difference of 10 feet in the respective levels of the running tunnels of the City & South London Railway; the ground in which they are situated consists in part of water-bearing strata; whilst, moreover, the siding and its connections with the running tunnels had to be formed without interference to the rapid operation of trains

through the latter. It was this last consideration that rendered the task of the engineers one of particular intricacy. Save for the leading-in section connecting with the « down » running tunnel — about 320 feet long and having a rise of 1 in 40 — the siding tunnel was bored by hand, at practically the same level as the « up » running tunnel (which is the higher of the two running tunnels), beside which it runs for a distance of 720 feet. Air locks had to be formed and compressed air resorted to in order to hold back the water in the bad ground.

To connect the leading-in tunnel with the « down » running tunnel, a junction tunnel of step-plate type was formed around a section of the latter, which, of course, had to be completely exposed. This step-plate junction leads off with 47 rings 21 ft. 2 1/2 in. in diameter, followed by 16 rings of 25 feet and 23 rings of 27 ft. 6 in., the three enlarging sections being eccentric to one another and having concrete end walls where they connect. The 27-ft. 6-in. section embraced also the mouth of the leading-in tunnel. The junction tunnel could thus take both the ordinary running track and the track that would diverge from it into the siding.

Meanwhile, the running tunnel, encircled as it was by the junction tunnel and somewhat to one side of the latter, was literally a tube, in the strict sense of the term. Trains were passing through it every two or three minutes. It was supported at the base and sides by heavy timber struts, placed in position with meticulous care as the earth was removed from around the tunnel. To prevent the compressed air escaping from the air lock into the tunnel, the holes in the segments of the latter (through which the grout had been injected when the tunnel was constructed) were plugged.

The connection between the siding tunnel and the « up » running tunnel was made at the point where the leading-in section joined the siding. Here the junction takes the form of a 27-ft. 6-in. tunnel, which contains the crossover road whereby the trains emerge from the siding into the « up » running tunnel. This junction, also, encircled a section of running tunnel, which, like the « down » tunnel, was supported by timber struts.

The final phase of operations was the dismantling of the enclosed sections of running tunnel and laying the floors of the junction tunnels. This work was conducted during the brief intervals between traffic. The old tunnels were removed, segment by segment, and the timber which had supported them at the base was left *in situ* and embedded in the concrete in which the new tracks were laid.

Some geological factors.

The worst section of ground on the course of the Morden extension was encountered at Tooting Broadway. The strata below the blue clay comprised Woolwich Beds (at a higher level than is usual in the London area), consisting of a layer of shell and shaly clay, which was hardened into a sort of natural concrete, whilst the strata of sand were waterlogged. Borings indicated that the lowest stratum of sand (in which the inverts of certain sections of the tunnels now lie) was in places 20 feet thick; the quantity of water here may be gathered from the fact that formerly artesian wells in the district were supplied from this source. The construction of a tube station in water-bearing sand — with its large-size platform tunnels, its escalator tunnels and passages, and, moreover, a siding and crossing — was thus a task attended by considerable difficulty.

Compressed-air operations.

Operations were conducted from three service shafts sunk above the site of the « down » running tunnel, to the south of the station. These shafts were excavat-

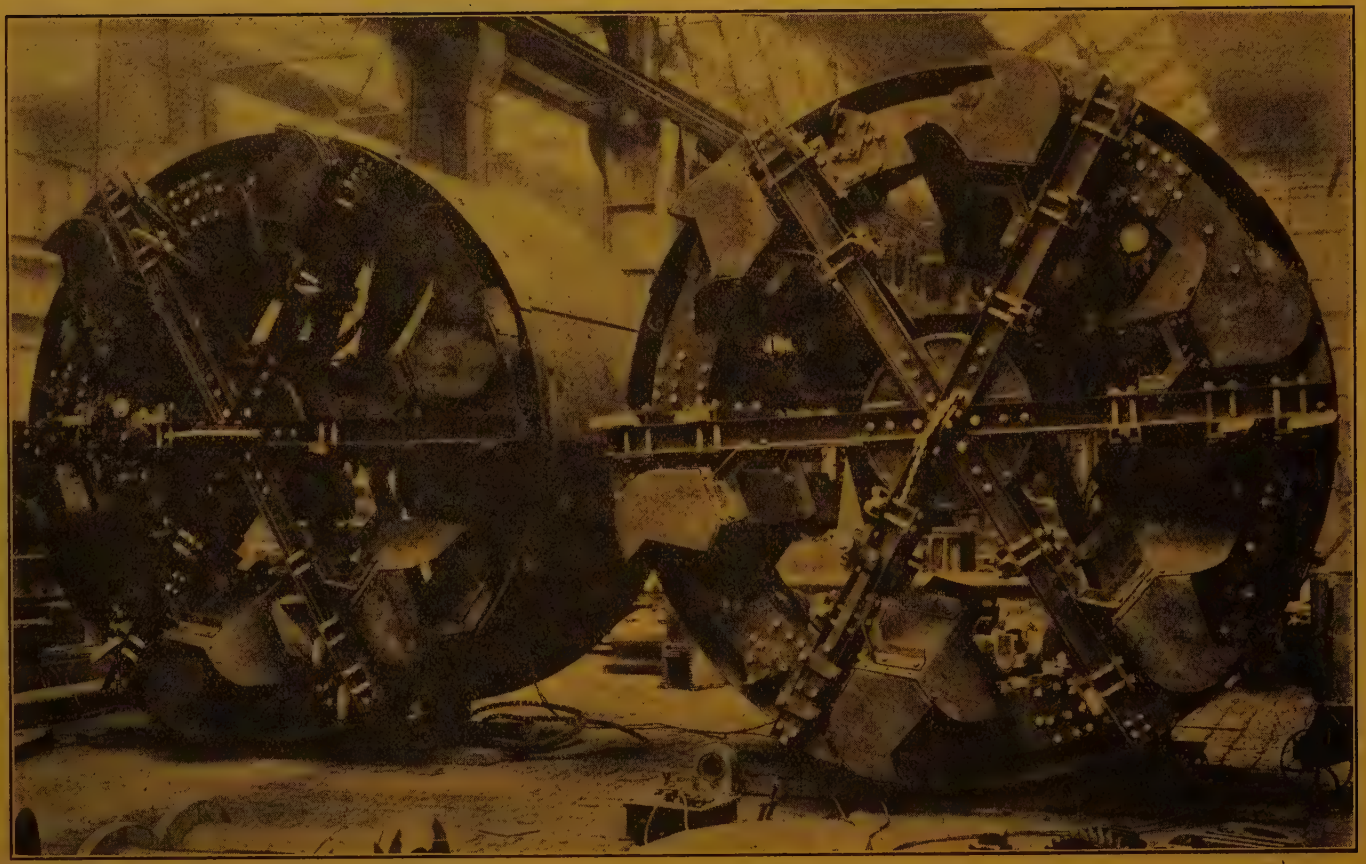


Fig. 6. — General view of rotary excavator shield.

Fig. 7. — Constructing reinforced-concrete cut-and-cover tunnels between Dorset Road and Morden Station.

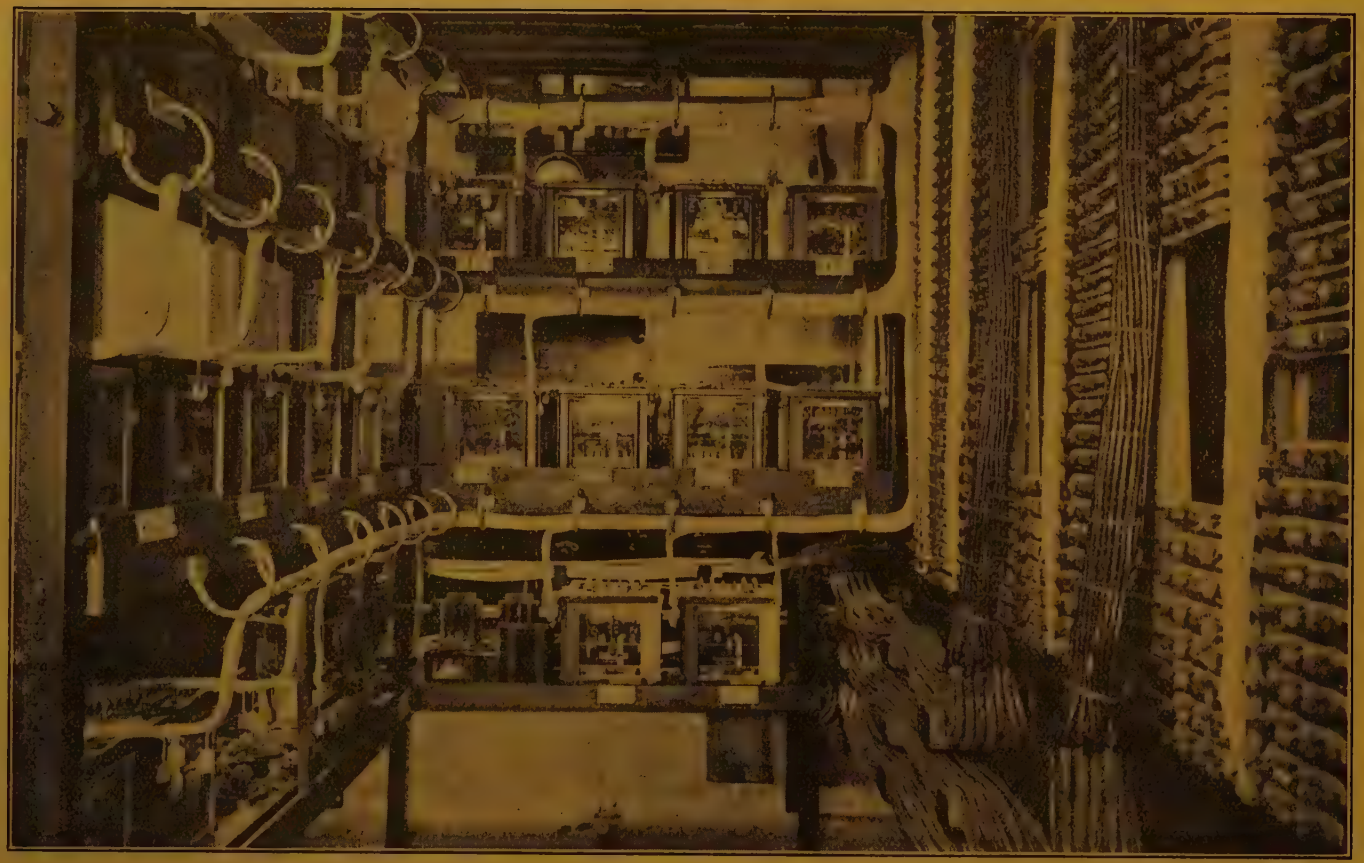


Fig. 8. — Relay room, Morden signal cabin.

Fig. 9. — Exterior view of Clapham South Station.

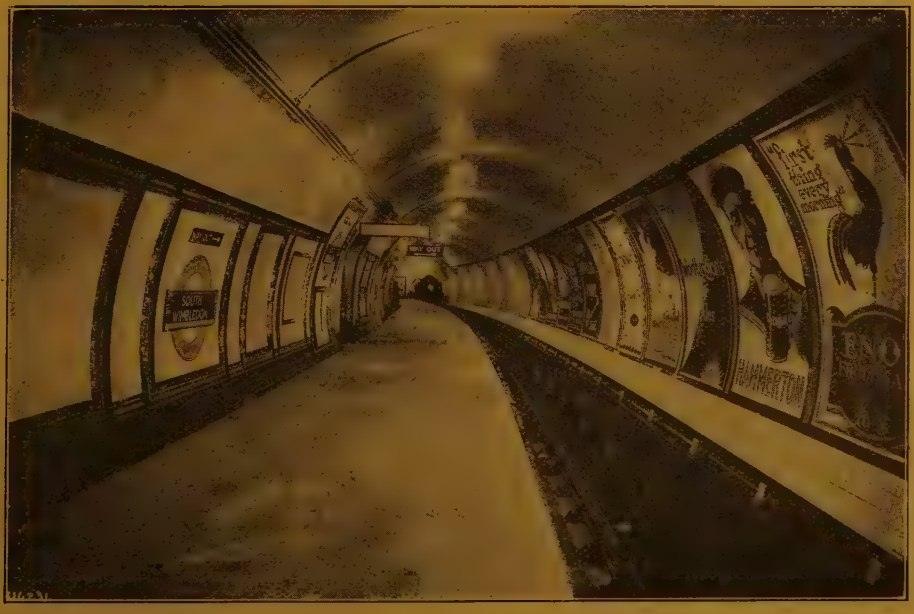


Fig. 10. — Plaform view in South Wimbledon Station.

Fig. 11. — General view of new car sheds at Morden.

Fig. 12. — Head of escalators, Clapham South Station.

Fig. 13. — Transferring the centre line below ground.

Fig. 14. — Power frame, Morden signal cabin.

Fig. 15. — Service shaft, showing the two plumb lines.

Fig. 16. — View in service shaft.

Fig. 17. — Centre line at the base of the service shaft.

Fig. 18. — Checking the level of the shield.

ed as far down as practicable without resort to compressed air. Vertical air locks were then fixed in the top of two of the shafts, and the sinking of the latter to the requisite depth of 50 feet was completed. Meanwhile, the third shaft was sealed at the mouth with a steel diaphragm.

The first phase of construction — comprising the step-plate junction that would link the « down » running tunnel with the leading-in tunnel of the siding, and a section of the similar junction on the « up » running tunnel — was then carried out under compressed air, through the vertical locks mentioned. The work on the « up » tunnel was begun from headings driven across from the shafts containing the air locks.

On the conclusion of the first phase the air locks and the diaphragm were removed from the service shafts, and four horizontal air locks were formed in the completed tunnels. Operations were then resumed under compressed air (at about 15 lb. to the square inch), and the platform tunnels, the running tunnels, the siding, the escalator shaft, and the various communication passages constructed. The air compressor plant maintained a continual supply equivalent to the conversion of from 2 000 to 2 800 feet of free air per minute.

The siding at Tooting is 425 feet long beyond the point, and can accommodate a full-length train, which, as at Kennington, enters from the « down » running tunnel and passes back into the « up » tunnel. The leading-in and leading-out sections that connect the mouth of the siding with the running tunnels on each side of it form a V in plan, and are linked with the siding by means of a junction tunnel of five sections, of decreasing diameter.

Permanent way and signalling.

The track equipment on the extension line is of the latest London Electric Railway standard. The running rails are of ordinary bullhead type, 95 lb. per yard, laid on cast-iron chairs screwed to jarrah sleepers. All crossings work is of manganese steel. Fibre pads are inserted between the chairs and the sleepers, to reduce noise in train running. The conductor rails are of special high-conductivity steel, carried on porcelain insulators. To promote cleanliness and to permit of the maintenance staff — and, in cases of emergency, passengers — walking easily along the track, the track in the tunnels is laid in concrete, which is flush with the sleepers. In the open at Morden the track is ballasted with granite. At Morden the lay-out comprises three platform roads, which converge at the south end into two roads leading to the depot.

The signalling installation on the new lines is in accord with modern « Underground » practice, and comprises electric lamp signals; electro-pneumatic train stops, working in conjunction with the signals; condenser-type track circuits; and electro-pneumatic point gear.

There are two cabins on the Morden extension : at Tooting Broadway and at Morden, respectively; and the cabin at the former terminal at Clapham Common has been adapted to automatic working. All signals between Clapham and Morden work automatically, except those controlled from the Tooting Broadway cabin when the latter is working. At times when it is unnecessary to reverse trains at Tooting the cabin here can be switched out, and the signals controlled from this point then operate automatically.

With the exception of the points at the entrance to the depot, the whole of the signalling at Morden is worked from the cabin there, situated at the northern end of the station. The points at the entrance to the depot are worked from a six-lever frame operated by the shunter. Movements to or from the depot are protected

Fig. 19. — Lay-out view of new car sheds at Morden.

by electrical interlocking between the ground frame and the power frame.

Both the Tooting Broadway and Morden cabins are provided with the latest type of power frames and safety devices, including an electrical lock on the point gear, which prevents the points being wrongfully operated. The frames allow for additional signals being installed. Each cabin has the usual illuminated diagram, which indicates the position of trains in the vicinity. Train describers are also installed, these notifying the signalman of the destinations of approaching trains. At Morden an improved platform indicator is provided, to inform passengers of the respective destinations of the next three trains and of the platforms from which they will depart.

At Kennington Station a new 31-lever power frame has been installed for working the greatly augmented lay-out at that place. This frame is so arranged that, if needful, it can work automatically, as in the event of all trains from the Hampstead line passing round the loop terminal here and all City & South London Railway trains working through to Morden. The illuminated diagram in the Kennington cabin embraces a total length of track of about 4 1/2 miles. The former southern terminal cabin of the Hampstead line, at Strand station, has been adapted for automatic working when required.

Power supply.

Current for operating the Morden extension is obtained from the County of London Electric Supply Company. It is received at a switch-house built by the « Underground » at Colliers Wood and thence transmitted to a sub-station at South Wimbledon, and also, through the latter, to another new sub-station at Balham. From these sub-stations the current — received as 3-phase alternating, at 11 000 volts, 50 periods, and transformed

and converted to the usual 600-volt D. C. — is passed to the rails.

Each of the sub-stations has Metropolitan-Vickers installations. South Wimbledon, which is of ordinary manual type (*i. e.*, operated by attendants), is equipped with three 1 200-kw. rotary converters, with corresponding transformers of air-blast type; extra high-tension and low-tension switchgear; and signalling, air-compressing, lighting, and ventilating plant. The Balham sub-station is of the remote-control type, after the style of the one in operation at Burnt Oak on the Edgware extension, but of much greater capacity. The installation comprises three 1 500-kw. rotary converters, with air-blast transformers, and the appurtenant automatic and ventilating equipment; also air-compressing, lighting and signalling plant, which will, however, be used only in case of emergency, such as a breakdown in the similar plant at South Wimbledon. Balham sub-station is controlled from South Wimbledon, whence the machines can be operated individually or together, from either or both of the two high-tension feeders, by means of switchers in the latter station. Once a machine at Balham is running it is protected by relays against every conceivable contingency. Both sub-stations are equipped with mechanical overhead travelling cranes. Space has been provided for additional electrical machinery, should the need for increased output arise.

Current for the Kennington loop is supplied by the « Underground » power house at Chelsea, through a new sub-station built beside the Lambeth North station of the Bakerloo Tube, in the Westminster Bridge Road.

The sub-station is of remote-control type, and the machinery is operated from the sub-station at Charing Cross. The equipment, of British Thomson-Houston design and manufacture, comprises two 1 500-kw. rotary converters, with air-blast transformers and other apparatus, and the usual auxiliary plant.

The tunnels of both lines have the usual device for cutting off current in cases of emergency. This consists of two wires, which extend throughout the tunnels and are insulated from the iron segments. These wires are connected through a tripping circuit with the track circuit-breaker in the sub-station from which the particular section of line is operated. When an exigency arises, a motorman can reach the wires from the cab of his train and by bringing them together open the circuit-breaker and thus cause the contact rails to become dead. The tunnels are fitted also with emergency telephone wires, communicating with the sub-station.

On the Kennington loop and in the tunnel section of the Morden extension the cables are carried on cast-iron brackets, bolted to the tunnel segments; in the Morden station cutting they are suspended along the retaining walls; whilst on the ground-level section they are supported on concrete posts.

The Morden depot.

The terminal depot of the Morden extension occupies a spacious site on the east of the Epsom road. The car sheds consist of a steel-frame structure of five bays, and are 426 feet long by 300 feet wide, with walls of stock brick and end gables faced with corrugated asbestos sheet. The steel-truss roof is covered with asbestos tiles. Roller shutters are fitted to all car entrances, so that in bad weather the sheds can be completely enclosed. Heating is provided by coke stoves. Adjoining, at the rear, is a wing containing an overhaul shop, stores, offices, mess-rooms, lavatories and other appurtenances. A footbridge, of reinforced concrete, 660 feet long with eight spans, the longest of which is 68 feet, affords the right-of-way formerly pro-

vided by a footpath across field at this point.

The depot has accommodation for 250 cars, and there is room at the rear for the sheds to be extended to take a further 84, if necessary. The car sheds contain 20 inspection-pit roads, each pit being 385 feet long and having capacity for 7 cars. Concrete ledges run along each side of the bottom of the pits, so that men engaged in inspecting or working on car trucks have two levels

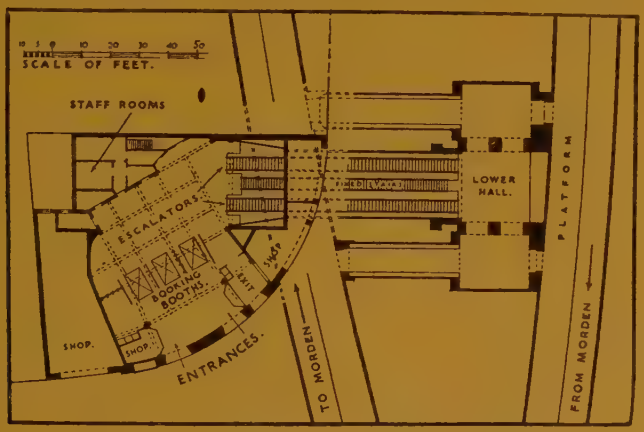


Fig. 20. — Plan of Tooting Broadway Station.

at which to stand under them — one, the ledges; the other, the « slot » between. Overhead trolley wires are provided. The cables suspended from them have adaptor terminals. Cars can thus be moved about over the pits by electric power. On the north side of the sheds are 5 stabling roads, for 41 cars; on the south side are 9 stabling roads, for 69 cars.

New stations.

The design of the stations on the new line has been evolved from one key elevation, which has been adapted to the peculiarities of the various sites and positions. In every case the material is Portland stone, with a canopy of reinforced concrete. This canopy has a blue enamel and bronze facia, on which appears the name of the station in white letters. A further touch of colour is imparted to the exterior by the window above the canopy, which bears the standard bulls-eye device of the « Underground ».

The cost of constructing the Morden extension and the Kennington loop was £4 750 000.

[625 .214 (.73)]

Roller bearings tested by the Chicago, Milwaukee & St. Paul Railway.

Figs. 1 to 3, p. 248.

(From the *Railway Review.*)

Tests conducted over a period of twe years have demonstrated the practicability of roller bearings of several types and their advantages over plain bearings; consequently, the Chicago Milwaukee & St. Paul Railway decided recently to make an extensive installation of roller bearing-equipped passenger trains. Sixty-four new Pullman cars and sixty-three cars of St. Paul ownership were ordered fitted with roller bearings. While both Hyatt and Svenska Kullager Fabrik bearings were tested with satisfactory results, the order for roller bearings for this equipment was placed with the Timken Roller Bearing Company, Canton, Ohio.

The experience of the St. Paul in testing roller bearings as compared to plain bearings was outlined recently by L. K. Sillcox, general superintendent of motive power, in a paper on the « Performance of roller bearings in steel passenger cars » read at the Chicago Milwaukee & St. Paul Railway annual car department staff meeting, held at Milwaukee, 20, 21 and 22 September. An abstract of this paper follows :

Among the advantages which test experience on the Chicago Milwaukee & St. Paul indicates may be expected of roller bearings as applied to passenger car equipment are: Reduced train resistance, practical elimination of rough handling in starting long trains, easier riding equipment, less chance of hot boxes, ample warning when defects develop, fewer slid flat wheels and a saving in lubricants. Another practical consideration is the possible elimination of different engine ratings for summer and winter where air temperatures have a wide variation.

While roller bearings have been discussed and considered for steam railway service during a period of almost twenty-five years the missing quality has always been that of durability, and designers of such bearings in their efforts to produce something suitable apparently erred on the side of giving the mechanics of the subject too much attention. They seemed to be interested chiefly in obtaining large contact areas, and in their endeavor along these lines, unfortunately neglected many other essentials, which were necessary in the development of this heavy type of bearing.

Eventually, it was realized that it was not sufficient to state simply that a bearing dealt with so many pounds load at a certain speed. The fatigue resisting properties and ability of the bearing to absorb and direct elements of side thrust under very difficult conditions of load and speed, needed consideration as well. Where the loads were high, but the speed low, the problem could always be solved by means of a ball-type bearing; but such bearings would have to be of dimensions quite impracticable in many cases, and necessitated redesign of truck frames and associated parts in order to accommodate the new construction. This fact, together with the higher cost of the bearing itself, presented a problem which has until re-

cently appeared insurmountable from a financial standpoint.

Roller bearings developed for standard truck design.

Months were spent on the Chicago Milwaukee & St. Paul endeavoring to develop a roller bearing which would take our standard truck construction. This was worked out by engineers of Svenska Kullager Fabrik Industries, Inc., New York, the final result being an assembly as illustrated in the drawing 1*a*. A standard cast steel truck frame was used and the only change made was that of applying straight equalizers rather than the curved ones, as in the past.

It will be observed that in the design of the cast steel pedestals, the pedestal legs were shortened to accommodate the new type box, and made considerably stiffer to eliminate the necessity of using a tie bar between them, sufficient rigidity being obtained to take care of the longitudinal thrust to which they are subjected. The method of applying the journal load through the straight equalizer and below the center line on the journal box, serves to keep the box in suitable alignment through the pendulum action of the load. The journal box is of cast steel, and since it is subjected both to tensile and torsional stresses, it has its heavy section around the load-carrying surface at the top, and stiffening ribs both at the top and around the bottom of the stirrup which carries the equalizer. The outer race of the bearing is in contact with the crown of the box through an arc of 150°. A forged shoe is dropped in the bottom of the stirrup to center the equalizer properly and secure it against motion longitudinally. A safety hanger is provided between the equalizer bar and the pedestal. Manganese steel pedestal liners are employed.

A design using bearings made by the Hyatt Roller Bearing Company, Newark, illustrated in the drawing 1*b*, has been developed and is operating under coach No. 4283. The drawing 1*c* shows the design of a four-motion journal box with Timken roller bearings, developed and adopted for use on the equipment just ordered.

From these drawings, a good idea may be gained of the types of bearings discussed. Both the Svenska Kullager Fabrik and Timken bearings employ rollers having a maximum pressure on the outside, thus forcing the oil toward the center and assisting constant lubrication. The Hyatt bearing has a plain roller, non-opposing and thus necessitates an end thrust washer to take the lateral strain.

Vital factors in roller bearing design for railroad equipment.

From the experience gained, it is our judgment that the selection of roller bearings should be made on the following basis :

1. Minimum friction.
2. Ability to deal with both thrust and radial loads.
3. Ability to deal with thrust load in one direction.
4. Ability to operate successfully for at least 1 000 miles after becoming initially defective, in order to allow a car to be brought to a terminal.
5. Ability to operate a minimum of 600 000 miles without failure of parts, wreck damage excepted.
6. The unit should be self-contained, with minimum number of loose parts, and should be non-adjustable.
7. The unit should be capable of quick inspection.
8. The unit should have the feature of self-alignment.

The ideal lubrication for an anti-friction bearing is a constantly circulating oil in an ample, but not too ample, vo-

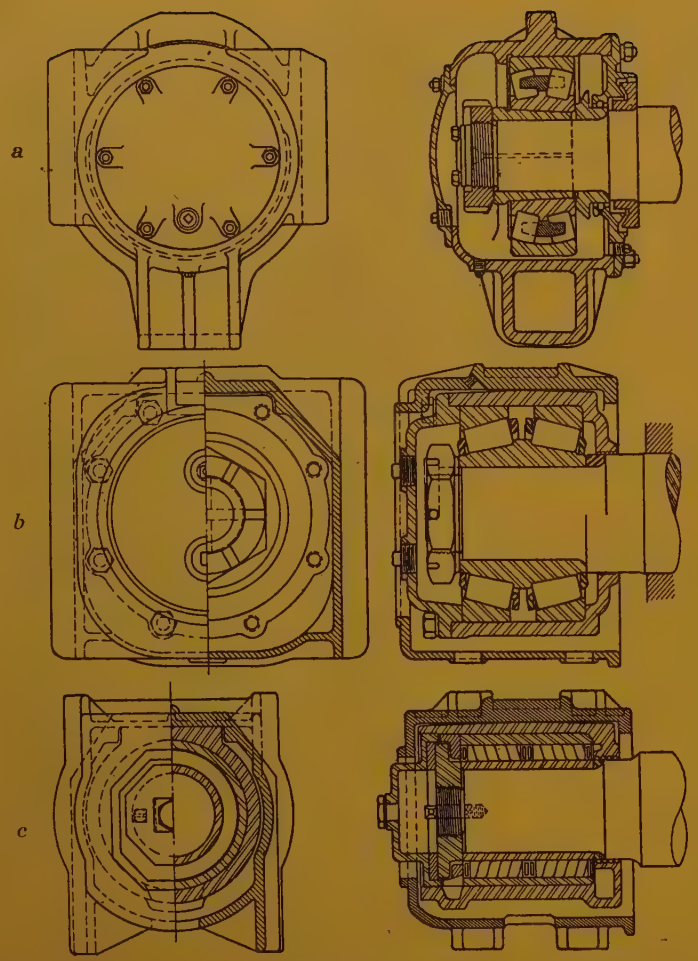


Fig. 1. — Types of anti-friction bearings.

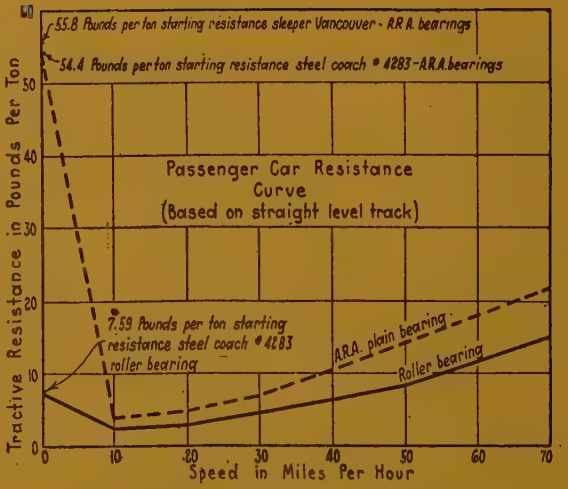

55.8 Pounds per ton starting resistance sleeper Vancouver - A.R.A. bearings
54.4 Pounds per ton starting resistance steel coach # 4283 - A.R.A. bearings
Passenger Car Resistance Curve
(Based on straight level track)
7.59 Pounds per ton starting resistance steel coach # 4283 roller bearing
A.R.A. plain bearing
Roller bearing
Tractive Resistance in Pounds Per Ton
Speed in Miles Per Hour
0
10
20
30
40
50
60
70

Fig. 2. — Roller bearings reduce starting and running resistance.

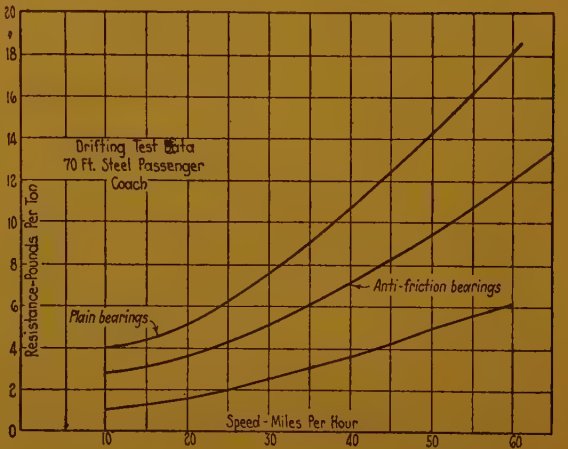


Fig. 3. — Power will be saved by drifting.

lume and with only slight pressure. Five main difficulties lie in the way of oil lubrication :

Heat is generated by the churning of the oil at speeds as low as 300-400 revolutions per minute (32-43 miles per hour) unless an overflow is provided to maintain a proper level. This churning and heating increases proportionately with the depth of the oil and the rate of speed.

Oil, being a liquid, is hard to retain in a housing. This is especially true because under the churning action of the moving rollers the oil is vaporized and is dissipated to a certain degree.

Owing to vaporization and other factors, oil requires renewal every six months or more.

When axles are not revolving, force of gravity draws the oil to the bottom of the housing, leaving the bearing dry and exposed to rust; filling housings full enough to cover the rollers at all times results in the above-mentioned churning and heating.

Oil is more expensive than grease.

From this it is apparent that, however proper oil lubrication might be, it is almost impossible to attain minimum rates of expense under the average service conditions.

As a result, grease is recommended generally for use where possible, at all speeds and temperatures and for all sizes of bearings. This does not mean that on some applications, oil will not give satisfactory service but that a proper quality and grade of grease on these applications should give equal, if not better, service with less trouble.

This recommendation is based on the following points :

1. Grease of the proper consistency does not work out of the housing.
2. Enclosure design is simplified.
3. Grease applied with a modern type of gun is kept perfectly clean.
4. Grease does not need as frequent renewals.
5. Grease does not sink to the bottom of the closure when the bearing is idle.
6. Suitable greases should be easy to obtain.
7. Since grease tends to fill the space between shaft and housing, it assists materially in keeping out dirt.
8. Under high speeds the rise in bearing temperature is less than with oil.

The essential properties of a suitable roller bearing grease are : *a*) Consistency a little stiffer than vaseline; this is important, as a grease of this consistency is stiff enough not to churn at high speeds, yet soft enough not to dry; *b*) no abrasive or body-giving matter, such as talc, graphite or pumice; *c*) mineral base; not vegetable or animal.

For a range in speeds of 300 to 840 revolutions per minute (32-90 miles per hour) a grease removal once a year is said to be ample. Under any conditions the most frequent renewal is every six months.

At the time of renewal the housing should be filled up until some of the old grease works out which can be wiped off. This is also a good time to note the quality of the grease last used and to see whether it has hardened. The tendency of grease to dry out is what really determines the frequency of lubrication.

Train resistances compared.

The best information which we have covering a comparison of resistance of cars equipped both with roller and plain bearings is shown in one of the charts (fig. 2). Our tests indicate that with steel sleepers the starting resistance may be as high as 55.8 lb. per ton; and with steel coaches 54.4 lb. per ton; while under the same conditions, at the same time, resistance of steel coaches fitted with roller bearings was 7.59 lb. per ton. Under these circumstances it

is possible to require in starting the Pioneer Limited, 15 cars, an effort from the locomotive of 67 200 lb. for equipment as fitted with plain bearings, as against 9 120 lb. required under these circumstances for equipment fitted with roller bearings, or, in the ratio of approximately 7 to 1.

From available information, it is clear that the greater the weight per coach, the lower will be the running resistance per ton and, consequently, the greater the proportional advantage of anti-friction bearings. It also seems clear that the lower the speed, the greater the advantage to be obtained with roller bearings. The chart referred to seems to bear out this point. Drifting results obtained with plain and roller bearings are illustrated in a second chart (fig. 3).

Granting the reduction in starting resistance that any good anti-friction bearing will make possible, the question then becomes, in my opinion, one of life and cost thereof. The utilization of the reduction in starting effort ought to bring about an entire change in motive power economics, but this will be a slow development with a good deal of resistance to be overcome. Those who have used roller bearings most extensively have been so satisfied with the practical results that they have thus far not been disposed to attempt to compare train resistance data through such elaborate tests as would be necessary. Therefore, they have only sought to confirm the known starting economy of roller bearrings.

One of the principal difficulties encountered in attempting to evalute the decrease in train resistance, due to the use of roller bearings, is the lack of a definite standard for comparison in the form of data representative of standard friction bearing equipment. There is no question but that the variation in the friction of the plain journal bearing is an important factor and tests have been made to show the effect of journal temperature on train resistance. Whatever figures are available make it apparent that the actual train resistance of plain bearing equipment is very indefinite except in terms of general averages interpreted as representative of normal conditions. On the other hand, our experience with anti-friction bearings has shown that the friction of the bearing is constant over a very wide range of speed and temperature conditions.

The inherent characteristics of the two types of bearings justify certain inferences. It is known that the efficiency of the plain bearings is determined by the factors that control the establishment of the oil film. This includes both temperature and speed, which are obviously variable in train operation, and is also dependent on unit pressures which will vary with the type of equipment. The resistance of the roller bearing is practically independent of temperature and speed, through such range as is experienced in train operation. An analysis of exhaustive tests of plain bearings which are comparable to those employed on car journals, indicates that only under most favorable conditions will the friction in a standard plain bearing compare favorable with that uniformly experienced with the roller journal bearing. Practical limitations preclude the normal operation of plain bearings under those favorable conditions, since the low viscosity of oil required, does not provide a sufficient margin against sudden incidental effects, which would lead to a further decrease in viscosity.

Brake action on roller bearing car.

The effect of roller bearings on brake action was studied recently, coaches as nearly identical as possible in weight, brake equipment and truck construction

except that one had roller and the other plain brass bearings, being tested at Western avenue, Chicago. Eight tests in all were made, the cars being stopped from various speeds with several different service and emergency brake applications.

It was observed that the wheels on the coach with roller bearings did not slide at any stop, while the rear wheels of the trucks on the coach with brass bearings slid at every stop made with an emergency application, the cause of the rear wheels sliding being due to the transfer of weight during the quick stop. This transfer of weight did not seem to affect the coach with roller bearings, however. The coach with the roller bearings ran a slightly greater distance, while subjected to the same applied brake force than the other car, but the difference was so small as to have no noticeable effect in controlling the train.

In connection with roller bearing applications, the importance of providing suitable hand brakes, buffers and draft gears, no preliminary spring action being required as at present to aid in starting trains, must not be overlooked. The advantages to be gained from drifting roller bearing equipped trains are readily apparent and should be studied in service with a view to relieving the engine and consequently the coal pile to the greatest possible extent.

MISCELLANEOUS INFORMATION

[625 .172 (.494)]

1. — Weeding railway lines,

By P. SCHENK,
ENGINEER, SWISS FEDERAL RAILWAYS.

Figs. 1 and 2, p. 253.

(*Bulletin technique de la Suisse Romande.*)

The lines of the 1st division of the Federal Lines have been weeded since 1921, either by mechanical means in the open country, or chemically inside station limits. The two methods are described in detail below.

I. — Mechanical weeding.

The Scheuchzer mechanical weeder was put into use in July 1921. After the first tests made in 1912 on the line between Lausanne and Echallens, the inventor of the machine, Mr. Scheuchzer, as a result of the appreciation shewn by the higher officials of the Federal Railways, improved the original machine which was improvised from the material available during the war, and eventually produced the machine which is now in use in several countries for weeding the lines.

Official tests attended by a dozen French and Swiss Engineers were made between Bussigny and Yverdon on the 8 October 1921.

The Chief Engineers, Mr. Ruffieux of the Paris, Lyons and Mediterranean Railway Company, and Mr. Dautry of the French Northern Railway, the Chief Engineer of the Midi Railway, Mr. Paschoud of the 1st division of the Federal Railways, and the inventor, with a number of the principal engineers of the same Companies, were present at the tests, which definitely proved the utility of the machine. The machine has since that time been put into use in France, Italy and Switzerland. The fact that it thoroughly works up the ballast, which cleans the track, and makes the maintenance easier, will be as much appreciated as that it pulls up the weeds, that is to say, does the weeding itself.

Description of the weeder (fig. 1).

A special flat wagon, fitted with a roof, carries a steam cylinder and the necessary control gear worked by compressed air to drive four sets of gear. The staff consists of a foreman and four men.

1. Three vertical knives pull up the weeds between the sleepers when driven down into the ballast between them : a hard steel wheel carried on a lever 30 cm. (12 inches) from the side of the rail mounts over or drops between the sleepers, thereby operating the shaft controlling the slide valve of the steam cylinder which raises or lowers the knives as these are above or between the sleepers. The driver lifts the knives out of the way when he approaches any obstacle, such as a level crossing, wall, bridge, piping, etc.

All earthing wires have been embedded more deeply so as to be out of reach.

2. A second set of gear controls a plough which weeds the ballast at the side of the line. It is lowered or raised by compressed air and is operated by a second driver. The forward movement of the vehicle itself causes it to plough up the sides, remove the weeds and their roots, and to rearrange the worked up ballast.

3. A third set of gear carried in the same frame as 2, works up the ballast between

Fig. 1. — Weeding train consisting of : the *Scheuchzer* weeder, one locomotive and the staff's mess carriage.

Fig. 2. — Weeding between Villeneuve and Roche, 21 August 1926. — Only one track is weeded.

two lines on double track lines, and removes the weeds : it is also pushed forward by the vehicle itself and lowered or raised by a compressed air piston and is operated by a third driver.

4. Finally, a metal rotating rake with long teeth, at the back of the vehicle, collects the weeds and levels the ballast to the proper line.

The locomotive which pushes the vehicle with its gear supplies the steam and compressed air required, and pulls the service vehicles on which are sleeping quarters, a kitchen and a small mess section.

The three vehicles travel at a speed of 4 to 5 km. (2.5 to 3 miles) when weeding, and at goods train speeds when the gear is not in use.

Based on these speeds and a 10-hour day, each Company draws up its weeding programme. The usual day's work is 20 km. (12.5 miles).

The cost of weeding mechanically, including the labour required to collect and burn the weeds, is 0.09 fr. per metre of single line, whereas hand weeding, as carried out before the war by gangs of men, costs 0.30 fr. and 0.50 fr. per metre (fig. 2).

The Scheuchzer weeder was used in 1925 as follows :

Switzerland	2 400 km.	(1 490 miles),
France	9 000 —	(5 590 —),
Germany	500 —	(310 —),

and will in future be more widely used on account of its efficiency, and also because of the double work it does in weeding and cleaning the ballast.

II. — Chemical weeding

As the mechanical weeder is not suitable for use in stations and yards where the sleepers are covered by ballast, and where there are many obstructions : platforms, points and crossings, rodding, pipe lines, signals, etc., weeding is done by chemicals. Various preparations, much lauded by their sellers, have been tried for a long time. After a temporary result obtained at a considerable cost, the weeds returned thicker than ever. During the last two years better results have been obtained by using chlorate of soda — instead of the many preparations put forward by the trade. The salt, in crystals or refined, dissolved in water at the rate of 1.250 kgr. to 1.500 kgr. to 100 litres (12.5 to 15 lb. per 100 British gallons) of water, according to the growth of the weeds, gives excellent results provided it is used before or after rain. The solution is sprinkled with ordinary watering cans when dealing with small areas. When large surfaces are to be dealt with, tubs of 2 to 4 m^3 (2.6 to 5.2 cubic yards) on trucks, with a hose pipe with small holes, placed 60 cm. (2 feet) above the ground, are employed. The best and most economical arrangement was found to be the use of an old tender on a condemned wagon as thereby 8 m^3 (10.5 cubic yards) of tank were available at little cost. One filling of water required a barrel of 100 kgr. (220.5 lb) of chlorate which is enough to destroy the weeds on 1 1/2 km. (0.9 mile) of line. The tank is fitted at both ends with unions to which flexible pipes fitted with ordinary watering nozzles can be fastened. Two men are required for the nozzles and four men to push the vehicle. This gang can cover 1/2 km. (0.3 mile) of track per hour in a station so that the cost becomes 0.07 fr. per metre of line. The price varies a little and depends upon the condition of the line, and also whether the work is done at a main or wayside station. In the latter case, the effect of passing trains and time to get from one station to another has to be considered. The special weed pulling vehicle has the advantage that it can be sent readily to any point, and that it is not necessary to prepare the solution before the work can be started.

The chlorate is not quickly soluble in cold water : by putting half the 100 kgr. of crystals into each of two sieves, the solution is made more quickly.

The chlorate of soda can be obtained from the Swiss works of Türgi and of Day, and from the French works at Chedde (Haute-Savoie) at prices of from 58 to 68 fr. the

100 kgr. When the demand increases, the price, owing to competition, should be reduced. One or two sections of the 1st division have used liquid *chlorate of lime* diluted with four times its volume of water for weed killing. 22 gallons of this solution are sufficient for 60 to 120 square yards. This salt was supplied by Swiss works at Monthey and gave good results, although not quite as cheap as with chlorate of soda. The solution in water takes less time, but as it has to be done more frequently owing to its weakness, the loss of time over-balances its lower cost.

Chemical weed killing with this material costs about 0.12 fr. per metre of track.

The inherent disadvantages of weed killing with chlorates are, firstly, the high cost of the salt, the labour to dissolve it, and the number of men required to apply it and to move the containers. In large stations, such as Renens, with 30 km. (18.6 miles) of track, the tank wagon ought to be hauled by a tractor at 3 km. (1.9 miles) an hour. Another disadvantage is the inflammability of the men's clothing when dry after having been saturated with the solution : great care is necessary. As a preventive measure, the Paris, Lyons and Mediterranean Company has supplied an overall in non-inflammable material in one piece, which the workman wears over his ordinary clothes. The material is very light and is made of horse hair fire-proofed, probably with a solution of silicate.

No rusting of rails, sleepers or fasteners, has been observed; rain dissolves and washes away any residue left on the metal. For good results, the weeds must be watered with the solution before they seed : the best time in Switzerland is between the 1 and 15 May, and should be done immediately after rain. It should not be done in dry weather.

[621 .116 (.42) & 721 .9 (.42]

2. — Reinforced concrete coal bunkers.

Figs. 3 to 5, pp. 256 to 258.

(*Engineering and Boiler House Review.*)

The reinforced concrete coal bunker may be said to be now thoroughly established, and its use is rapidly increasing in those industries where large quantities of coal have to be stored above the ground level. One of the most modern examples for boiler house work is the recently completed 10 000-ton bunker at the Greenwich Power Station of the London County Council Tramways Department, and we propose to give some further details of this particular structure in the present article; but before doing so we will deal with some of the advantages of this form of bunker construction.

Strength and elasticity are two marked characteristics of reinforced concrete, which also possesses the valuable property of increasing in strength and durability. It also combines the structural advantages of rigidity, impenetrability, impermeability, resistance to fire, and economy both as regards first cost and the elimination of the maintenance charges necessary in the case of all other structural materials. Other advantages are to be found in the rapidity with which works can be executed, and in the fact that the constituent materials are readily obtainable in all districts, the steel requiring little preliminary workmanship, and the sand and aggregate for the concrete being frequently available in the vicinity of the works to be executed.

Reinforced concrete structures differ from those erected in accordance with ordinary methods in the respect that the entire fabric is of monolithic character, the concrete being in perfect connection throughout, and the steel affording a further assurance of continuity and mutual action between the various members or structural elements. Therefore any well designed and properly built reinforced

concrete structure is capable of acting as a single unit in case of emergency, and if unexpected local stresses are suddenly developed by earth movements or any accidental cause, the integrity of the structure is maintained in consequence of the aid which is rendered by contiguous structural members to the part affected.

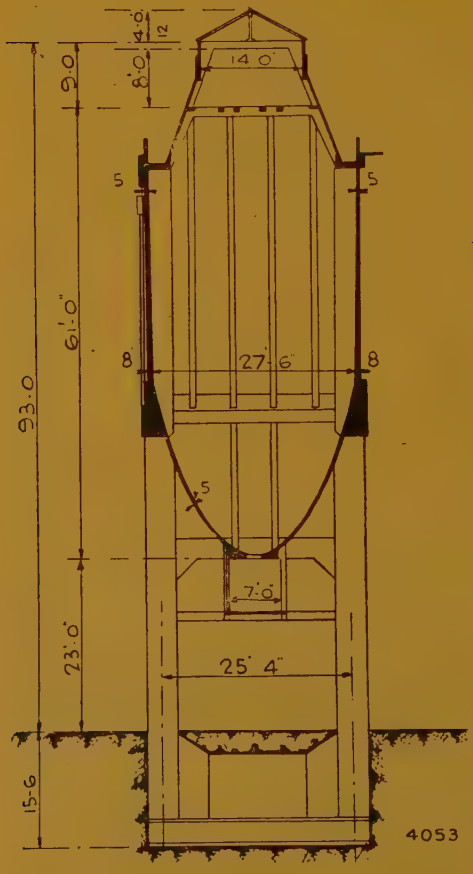


Fig. 3. — Vertical cross section through bunker.

Another distinctive feature characterising all reinforced concrete structures is that of lightness or slenderness, in comparison with the heaviness or massiveness of plain concrete, brick, and masonry structures. Due to the elastic strength of the combination, the engineer is able to depart from the custom of employing material in heavy masses, and to adopt forms of design akin to those found in steel construction. Apart from the gain of interior space in buildings, reservoirs, and structures intended for storage purposes, important economies are effected by this method of design. The saving of material in the superstructure naturally has the effect in reducing the load to be transmitted to the earth, thereby reducing the cost of foundations, and obviating the difficulties which frequently occur in work of the kind.

In reinforced concrete work the use of broken stone gravel or other hard material is necessary in order to produce concrete of adequate strength and durability, and for the same reason Portland cement is employed as the cementitious material, instead of any of the varieties of lime and other cements which are still largely used in ordinary construction. The grading of the sizes of the individual pieces which form the aggregate is a matter of prime importance. It will be readily undertood that in a heap of broken stones each individual stone, say 2 inches in diameter, will form a mass which is not solid, because of the gaps or voids between the stones themselves. If, however, a proportion of smaller stones, graded in sizes to fill these voids, is mixed with the 2-inch stones, then the original heap will more nearly approach a solid mass. To go one step further, and mix the original stones with smaller graded stones, and, in addition, add a proportion of sand, then the resulting heap, if the mixture is properly graded, will approach to the ideal solid mass which is aimed at for a good concrete mixture. Cement, of course, is finally added as the binder, when, after mixing with water, the very fine cement fills up the tiny voids between sand particles, and the sand-cement mixture fills up the voids between the larger stone pieces. All the particles, large and small, should be well coated with sand cement mixture and cement respectively, and when the cement hardens by a process of chemical reactions the whole solidifies into a compact crystallised mass.

The new coal bunker at Greenwich is a mo-

dern example of the pure reinforced concrete design. The bunker capacity is 10 000 tons of coal, having an overall length of 340 feet; height 100 feet, and width 30 feet. The bunker is divided into eleven separate compartments which can be loaded or emptied independently. This latter feature not only gives useful structural strength, but in addition it provides a safeguard in the event of spontaneous combustion in the coal, by keeping the overheated portion isolated and under separate control. The general structural features will be clear from the illustrations which have been prepared from drawings kindly provided by the designers and contractors for the work, Messrs. Industrial Constructors, Ltd.

Fig. 4. — View of completed bunker.

The coal handling plant which consists of a series of conveyors is capable of transferring coal from the boats or barges in the river to a conveyor running along the top of the bunkers, thus discharging the coal into same; it is also capable of receiving the coal from the hoppers and conveying it back to the steel bunkers in the power house which feed the mechanical stokers on the boilers.

The London County Council opened this particular problem of coal bunkers by inviting competitive designs and tenders from most of the reinforced concrete specialist firms. Industrial Constructions, Ltd., won the competition, their tender being the lowest received for a satisfactory design. The three points which were particularly weighed in deciding the matter were :

a) The positions chosen for the large concrete columns, which had to penetrate through workshops, mess rooms, lavatories, and other additions to the main power station building;

b) The most important factor; that a clear space was required for the coal in each of the bunkers without the interference of cross ties. On account of the very large dimensions of the bunkers, it became very difficult to devise means to take the heavy pressures without introducing ties near the bottom of the bunkers; this difficulty was overcome by making the bottom of the bunkers parabolic in shape; the thrusts at the top of the parabola being taken by the heavy mass of concrete reinforced as a beam spanning between column and column. The parabola was chosen because of its simplicity in construction and the fact that it eliminates very largely the secondary stresses and carries the whole of the load and pressure by a skeleton of tensile reinforcement clothed with 5 inches of concrete;

c) The architectural treatment of the elevations.

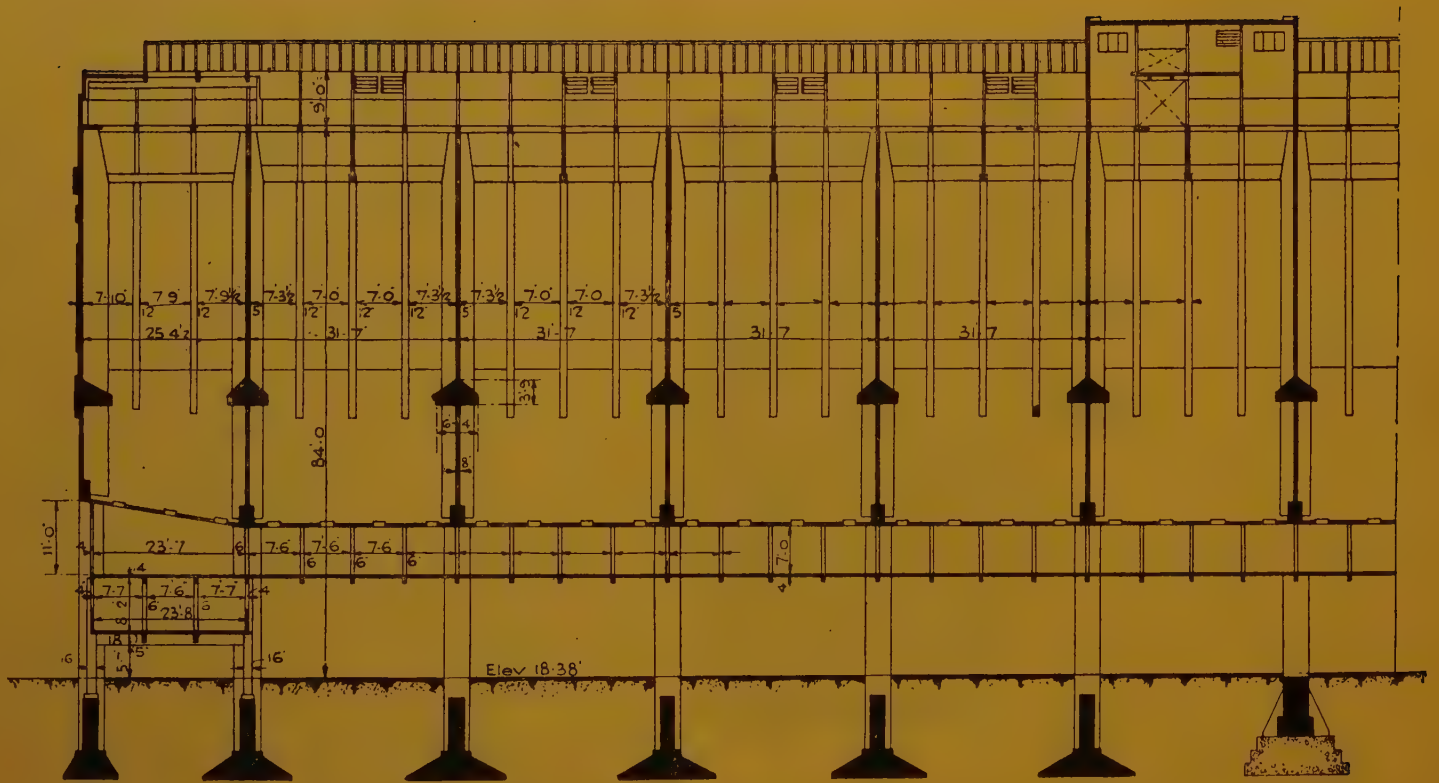


Fig. 5. — Part longitudinal section through bunker compartments.

The general depth of the foundations was 15 ft. 6 in. below the yard level, although in some cases it was necessary to go deeper. The foundations presented many difficulties on account of the confined site and the necessity of excavating below and underneath existing buildings.

Regarding the execution of the work, the following notes are of interest. The whole of the timber shuttering was made on the site. The steel reinforcement was of British manufacture and delivered to the site by rail and road, bent ready to place in the timber forms. The aggregate, sand and cement, was delivered to the site by water in barges, and in the case of the aggregate and sand unloaded by a grab working from a 3-ton derrick crane and discharged into timber bunkers, and in the case of the cement unloaded by slings from the crane and put direct into cement store. The concrete generally consisted of four parts of aggregate, 3/4 inch to 1/4 inch, two parts of sand to one part of cement, although that in the columns consisted of a 2. 1. 1. mix. All the plant was electrically driven, the hoists consisted of two « Insley » masts and the concrete was mixed in two « Zenith » mixers.

The structure was designed in accordance with the L. C. C. regulations and complete calculations and working drawings were submitted to this Authority and their approval obtained.

[621.138 2 (.42)]

3. — New mechanical coaling and sanding plant at Doncaster.

(*The Railway Engineer.*)

Figs. 6 to 10, pp. 260 to 264.

By the courtesy of Mr. H. N. Gresley, C.B.E., Chief Mechanical Engineer of the London & North Eastern Railway, we were recently enabled to visit the Carr locomotive sheds at Doncaster, and there witness the operative methods followed in fuelling locomotives by means of the mechanical coaling plant recently installed. The apparatus consists of a patent wagon tippler hoist designed and supplied by The Mitchell Conveyor & Transporter Co., Ltd., of Holborn Viaduct, London.

This coaling and sanding plant is adaptable for elevating railway wagons up to 20 tons capacity to a height of 60 ft. 6 in. above rail level, at which point the coal is discharged into an overhead bunker of 500 tons capacity. The bunker is divided for two qualities of coal, and separate bunkers are provided for the storage of 20 tons of dry sand for locomotive use.

In operating the plant the loaded coal wagon is detached from others and runs by gravity on to the cradle immediately in front of the coaling tower, and the attendant then manipulates a barrel-type controller which starts up the winch and causes the cradle to be hoisted. Immediately the cradle begins to rise, the wagon tilts slightly sideways and leans gently against a padded side support running the whole length of the wagon, at the same time holding it in such a way that it is impossible for the wagon to leave the track. In this position it is hoisted to a point above the coal bunker, where the lower or inner side of the cradle is arrested, and as the winding process continues the cradle and wagon continue to rotate until the coal has been completely discharged. During this period of rotation at the top of the bunker a sustaining beam takes the whole of the supporting weight off the sides of the wagon, which is thus held entirely by the beam passing longitudinally over the wagon. This beam is so arranged that wagons of every size have a larger clearance for big coal discharged between the sustaining beam and the edge of the wagon. The wagon being emptied, the controller is moved to the return notches, and the reverse of the cycle of motions described above takes place. Wagons are hoisted, tipped and returned to

ground level in less than four minutes, so that, making allowance for shunting them on and off the cradle, coal is filled to the bunker at the rate of 240 tons per hour.

Fig. 6. — General view of the mechanical coaling and sanding plant.

The bunker is of ferro-concrete construction and arranged to support all mechanical and structural parts attached to it. It is divided into three compartments, the two outer ones having a capacity of 167 tons each, and the inner one 165 tons, and is shaped so as to discharge the contents of each compartment through twelve sets of valves and chutes to the locomotive tenders.

The foundations consist of square piles measuring 12 by 12 inches driven in groups of four to a depth of over 22 feet, each group being covered by a cap of reinforced concrete forming the feet of the columns spporting the plant. The structure is compactly arranged and occupies a minimum of space, the length being only slightly in excess of the longest wagon to be tipped, and the width suitable to the existing conditions of site.

The storage bunker is filled in a little over two hours, and one man only per shift is required to coal all the engines at the Doncaster running sheds. An important saving is effected in locomotive hours by the rapidity with which engines are coaled and returned to duty, thus increasing their earning capacity, whilst a freer circulation of wagons is rendered possible. The coal is measured as

Fig. 7. — Coaling and sanding *Pacific* class express engine at Doncaster.

Fig. 8. — View of plant from bunker-loading side with 2-6-0 type engine after being coaled and sanded.

Fig. 9. — Wagon being lowered after discharging coal into bunker.

Fig. 10. — Wagon in discharging position at bunker level.

it is delivered to the tender, and a record kept of the amount received by each engine. The cradle and the wagon, and a portion of the coal being balanced, the winch has only to deal with the remainder of the load, thus reducing the power consumption to a minimum.

Owing to the small amount of steelwork requiring painting, and to the fact that the concrete bunker is the only part that actually comes in contact with the coal and sand, the maintenance charges should be very low. As the machine automatically adapts itself to the different sizes of wagons and loads, any wagon in use on the London & North Eastern Railway can be handled in any sequence without the need for hand adjustment.

The arrangement for supplying sand to locomotives is a special feature of the plant. The sand is discharged from wagons to a dryer from which it is elevated by air compressors to two ferro-concrete sand bunkers arranged at each end of the top of the coal bunkers, and sand is supplied direct to the locomotive sand boxes without interrupting the process of coaling.

One of the accompanying illustrations shows a Pacific type express engine of Mr. Gresley's design being coaled and sanded at the same time. It is worthy of note that the sanding part of the plant is embodied in the design without increasing the overall dimensions of the installation, this resulting in valuable space being saved in addition to considerable reductions in operating costs compared with the labour usually required at sand furnaces.

A large number of coaling plants of the kind illustrated and described are now in operation, and have been steadily improved in efficiency, with the result that the costs of operating and maintenance have been reduced to a minimum. As we have before remarked in connection with large locomotive running sheds, apparatus which tends to reduce the amount of time and labour required for coaling, sanding or otherwise attending to locomotives may be regarded as a necessary adjunct to the work of the depot and one which results in an important ultimate economy being achieved.

[621 .134.1 (.73)]

4. — The Martyn balanced piston head.

Fig. 11, p. 266.

(*Railway Age.*)

The Martin balanced piston head, the detailed construction of which is shown in the drawing is designed with the principal object of lifting the weight of the piston off the bottom of the cylinder, thus reducing to a considerable extent the amount of wear on both the piston head and cylinders. The piston head is a hollow casting with inside reinforcing ribs. The sand cores are removed through the five cored holes shown around the inside circumference on the face of the piston head. All of the holes, except the bottom hole, are drilled, tapped and plugged. The bottom hole is used for the balancer steam valve, a cross section of which is shown at the lower left corner of the drawing.

The balancer consists essentially of three separate pieces made of tool steel. The steel ball *A* which serves as a floating valve is a fourth piece. The hole in the piston head for the balancer is tapped with a special tap somewhat similar in design to a staybolt tap. The balancer casing is threaded as shown in the drawing. Twenty tapered holes *B* are drilled in two parallel rows around the center of the casing for ports to allow steam to escape from the balancer casing into the cored cavity in the piston head. The balancer casing is tapped at both ends for plugs which serve as seats for the ball *A*. These plugs are drilled through the center for steam ports, the outside end of the hole or steam

port being made square for the insertion of a square end wrench. In order to obtain minimum wear on the ball *A*, as well as efficient operation of the balancer, the ball is allowed 1/12 inch roll or travel. This travel is regulated by screwing the plugs in or out as necessary.

As the piston moves forward the ball *A* is seated against the rear plug by the pressure of the steam, and steam is allowed to enter the cored cavity in the piston head through the ports *B*. Steam pressure is built up in the cavity and thence through the port *C*, which is drilled in the piston head directly

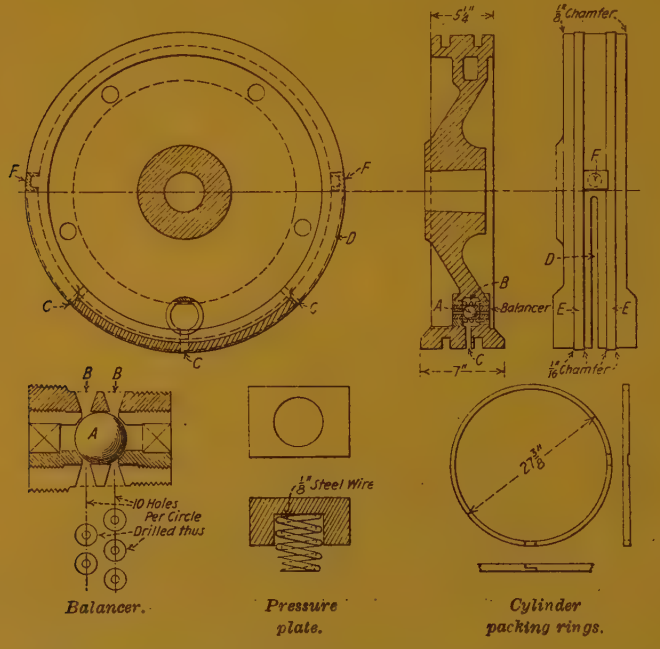


Fig. 11. — Piston head designed so that the weight is carried on a cushion of steam instead of on the bottom of the cylinder.

under the balancer. A groove *D*, machined around the underside of the piston head, permits the steam to fill the space between the pressure plates *F* and the packing rings. The pressure built up in this space is sufficient to lift the piston and piston head. The pressure plates F are forced out against the walls of the cylinder by a 1/8 inch steel wire spring.

It is reported that piston heads of this design have been in operation for over a year on locomotives being used in both freight and passenger service and are rendering good service, particularly in reducing piston and cylinder wear. The inspection at the end of the year showed that the top cylinder walls had acquired a polish in all cases. One superheated locomotive was operated for nine months, 16 hours a day, with an average train load of 74 cars. At the end of this time the observers reported a total wear on the piston head of 3/32 inch.

[656 .253]

5. — Lever operated switch for use with cab signalling ramps on single lines.

Figs. 12 and 13, p. 268.

(*Les Chemins de fer et les Tramways.*)

The French Government has issued an order requiring the principal French Railway Companies to fit their locomotives with cab signals for repeating all signals and semaphores.

The cab signal uniformly adopted is operated by a metal brush carried on the engine, when passing a signal, making contact with a fixed insulated conductor in the form of a ramp in the middle of the track.

The ramp is connected to a battery through a switch fitted on the signal, the current being on or off, depending upon the position of the signal.

Most of the railways only repeat signals that are in the « on » position; when the engine passes a signal in the « on » position the contact of the brushes with the ramp electrically operates a special whistle placed on the locomotive and records in some suitable manner that the apparatus has operated.

On double lines the ramp circuit is fairly simple : the positive terminal of the battery is connected to the ramp through the switch on the signal, while the negative terminal is connected directly to the rails of the adjacent line.

When an engine passes the signal in the « on » position, the current passes through the brush and the electrically operated alarm gear, and the frame and wheels of the engine.

The problem is more complicated in the case of single lines, because the signals only affect trains running in the direction for which they are provided.

In cases where the signal is « on », the driver can easily discriminate between the signals which do or do not apply to his direction of running, by the colour of the disc in daylight, or the coloured lights of the signals at night.

Moreover, wherever possible, the signals are placed on the left-hand side in the direction of running, which makes the sighting easier.

When dealing with the repetition of signals in the cab, in order to avoid confusing the driver, it is desirable that only the ramp corresponding to the signals which apply to the particular direction of running should be energised at the moment they are passed over by an engine running in that particular direction.

Ramps which are passed over in the opposite direction should not under any circumstances set the repeating device in operation.

The method generally used to obtain this result on single lines is to insulate sections of rails at the approach to the ramps and connect them to relays, so designed that the repeater circuits are broken when trains pass over the ramps of signals applying to the opposite direction of running.

The provision of this arrangement entails an additional cost of as much as 4 000 to 5 000 fr. per installation when the track is provided with steel sleepers, for in this case the steel sleepers have to be replaced by wooden sleepers at the insulated sections.

The « Compagnie des signaux et entreprises électriques » has developed a track switch with which the circuit is broken by the depression of a lever by passing wheels, and remains open a pre-determined time.

This type of lever-operated track switch appears to solve the problem of the repeating of signals on single lines in a simple and inexpensive manner.

When one of these switches is installed a few yards beyond a signal, it is only necessary to connect it to the corresponding ramp to ensure that, when the ramp is passed over in the reverse direction, the cab signalling appliances will not act.

Actually when the lever is depressed by the leading wheel of the engine, the circuit is broken and remains open for several seconds.

Therefore, in this case, at slow speed, the brush makes contact with the de-energised

ramp. The ramp is automatically energised a few seconds after the train has passed.

When approaching a signal in the right direction, the lever is pressed down after the brush has passed over the ramp; the cab signalling apparatus therefore works normally as if no switch were provided. The ramp circuit is opened, it is true, as in the foregoing case but, by reason of the relative positions of the switch and the ramp with respect to the direction of running, the breaking of the circuit does not matter.

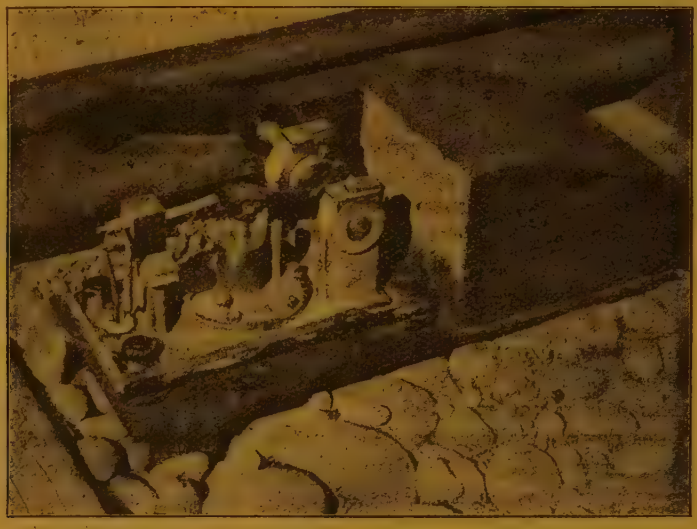


Fig. 12. — Time contact lever.

Figure 13 is a diagram of a layout of a track circuit breaker. This apparatus consists of a lever AB pivoted about a spindle O perpendicular to the base.

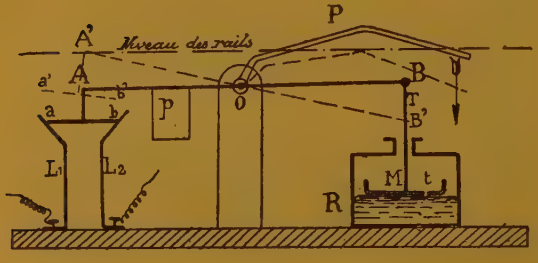


Fig. 13. — Diagram of lever track circuit breaker.

Explanation of French terms: Niveau des rails = Rail level.

This spindle carries a metal lever P in the shape of an inverted V which, in its normal position, projects slightly above the level of the rail against which it is placed, so that it is pressed down by the portion of a tyre which projects over the outer edge of the rail.

The lever is connected at its end B to a piston M in the form of a cup pierced by a small orifice *t*.

The end A carries a copper contact which normally connects the two blades L_1 and L_2, and thus completes the electric circuit.

The piston M works in the cylinder R, at the bottom of which is placed a certain amount of mercury.

The counterweight *p* serves to balance the lever.

The operation of the apparatus is as follows:

The lever P is depressed by a wheel passing over it, and by rotating the spindle O depresses the arm AB. The contact *ab* is broken, the piston M plunges into the mercury with which

the cup is filled, thereby destroying the equilibrium of the lever and holding it in the inclined position A/ B/.

As soon as the lever P is released by the wheels, the counterweight *p* tends to bring back the lever to its normal position; the mercury which fills the cup of piston M escapes gradually through the orifice *t* and lever AB returns slowly to its normal position. When all the mercury has run out of the cup, the circuit is again closed.

By varying the size of the orifice *t*, the time during which the circuit remains broken can be adjusted.

In later models, the « Compagnie des signaux et entreprises électriques » has, in order to reduce the cost, replaced the mercury by an unfreezable viscous liquid which operates in the same way.

Figure 12 is a photograph of a delayed action contact maker.

E. G.

[385 .524 (.71)]

6. — Premium payments abolished in Canadian National Railways shops.

(*Railway Review.*)

Abolition of the bonus or premium system in all shops of the Canadian National with the payment from 8 December 1926 of an increase of two cents per hour to employees thus affected, is announced in a statement made public on 5 December by S. J. Hungerford, vice-president in charge of operation.

The statement follows :

« Following the amalgamation of the various railways now constituting the Canadian National Railways System, there was found, as would naturally be expected, many variations in practice and method. Obviously, uniformity was both necessary and desirable under the new conditions and the management has been progressively studying each of the questions involved with a view to selecting that method which was considered the best available for the particular purpose, or, as an alternative, the development of an entirely new one for adoption throughout the system.

« Among the many variations in practice, it was found that at some of the older repair shops, a so-called premium payment plan had been in vogue, to a greater or less extent for many years, whereby those working under the plan were paid an amount in addition to the regular hourly wage, for output in excess of an established standard, whereas in the shops on the greater part of the system, the usual hourly wage system only was in effect.

« At the beginning of 1925, a plan of co-operation between the federated shop trades and the management of the Canadian National Railways was inaugurated which had, among other objectives, the more efficient operation of shops; stabilization of employment as far as practicable; and the study and development of those matters related to shop operations of mutual benefit to employer and employees. To this end, committees consisting of a substantially equal number of foremen or other local supervisory officers and representative workmen selected by the employees themselves in the respective shops, have since held meetings at regular intervals, at which all suggestions relating to the work and surrounding circumstances excepting wages and conditions related thereto, have been studied and discussed, with the result that substantial improvements of mutual interest to both parties to the plan have been secured. In addition to the various local mixed committees, a similar committee has been established on each general manager's region and also one for the entire system, to deal with questions of a general rather than a local character.

« The operation of the cooperative plan has now reached such a stage that the bonus system has ceased to be either advantageous or attractive. Therefore the management regards it as eminently just that the premium system should be abandoned and an appropriate bonus,

in addition to the hourly rate, be paid, as a recognition of their cooperative effort, to all employees of the Canadian National Railways in the mechanical department covered by wage agreement No. 6, between the Railway Association of Canada and the federated shop trades.

« Therefore, in pursuance of this decision, the bonus or premium system is abolished in all of the shops of the Canadian National Railways, and effective 8 December 1926, all of the employees referred to in the above paragraph will receive an increase over and above their present hourly rate of two cents per hour, in lieu of the premium previously disbursed.

« Under the new method, the company will not pay the workmen, in the aggregate, any more than has been paid hitherto, and in addition will secure certain other economies. Having regard to all of the factors involved, it is confidently believed that this change in practice will, on the whole be of benefit to both the railway and the employees concerned. »

NEW BOOKS AND PUBLICATIONS

[624. (01 (.43)]

DEUTSCHE REICHSBAHN-GESELLSCHAFT (GERMAN RAILWAY COMPANY). — **Vorschriften für Eisenbauwerke. Berechnungsgrundlagen für eiserne Eisenbahnbrücken. Amtliche Ausgabe (Official Regulations dealing with the calculation of Steel Railway Bridges).** — One volume (12×8 1/4 inches) of 54 pages with 14 appendices and numerous tables and figures. — 1926, Berlin, Wilhelm Ernst & Sohn, Publishers. — Paper backed : 3 Rm.

The instructions in the latest Regulations of the German Railway Company to which metal railway bridges are to be designed and built are little different from those in the Regulations issued in 1922 by the German State Railways of which a detailed review was given at the time (1).

The most valuable and noteworthy details of these instructions are given below.

Rolling loads. — The calculation of railway bridges, it will be remembered, is based on the effects of three differently made up trains, train N with 25 t., train E with 20 t., and train G with 18 t., axle loads according to the importance of the line under consideration (24.6, 19.7 and 17.7 English tons respectively).

Train N is made up of two tank locomotives with 7 axles of 25 t., 1.60 m (5 ft. 3 in.) apart followed by high capacity bogie wagons (bogie of 2 axles of 20 t., 1.50 m. (4 ft. 11 1/16 in.) apart.

Impact. — The stresses due to the *increases in loading* acting vertically should be multiplied by *a coefficient of dynamic augment* φ — Stosszahl.

This coefficient diminishes with the span and varies according to the design of the structure.

In the two extreme cases : 1. rails laid directly on the stringers or main girders with the usual type of joints, and 2. continuous rails without joints or welded, laid on ballast, the coefficients φ are the following :

1. $\varphi = 1.2 + \frac{17}{l + 28}$ with $\varphi_{max.} = 1.8$ with $l = 0.00$ m. ;

2. $\varphi = 1.00 + \frac{60}{l + 150}$ with $\varphi_{max.} = 1.4$ with $l = 0.00$ m.

For a span of 150 m. (492 ft.) the increase due to impact may be as much as 30 % in the first and 20 % in the second case.

Tables. — The new instructions contain tables of moments and reactions for use when making calculations of girders supported at the ends, and of details of the structure.

Footways. — The service footways should be calculated to carry 400 kgr. per square metre (82 lb. per square foot), and the handrail to stand a lateral thrust of 50 kgr. per lineal metre (100 lb. per yard). If these footways are open to public use the loads should be 500 kgr. per square metre (102.5 lb per square foot), and 80 kgr. per lineal metre (161 lb. per yard) respectively.

(1) See *Bulletin of the International Railway Congress*, number for October 1923, p. 916.

Station platforms should be calculated for an individual moving load of 1 t. (0.98 English ton) taken as occupying a space of 1 m. × 2 m. (3 ft. 3 3/8 in. × 6 ft. 6 3/4 in.) and a uniformly distributed load of 500 kgr. per square metre (102.5 lb. per square foot).

Variations of temperature. — Variations of ± 35° C. (63° F) on either side of a mean temperature of + 10° C. (50° F.) are to be allowed for. Allowance is also to be made for differences of temperature between certain details due to unequal heating of the structure. These differences may be as much as 15° C. (27° F.).

Braking. — The longitudinal reaction due to braking is equal to 1/7th of the whole axle load on the bridge. This reaction acts in the direction of movement of the train.

In calculating the reactions at the abutments, the friction of the rockers should be taken into account. In every case the component through the rocker must not exceed that through the fixed support

Nosing. — The live force due to nosing is taken as equal to 6 tons at the front coupled axle of the locomotive. The stresses due to braking and nosing are not to be increased by the dynamic coefficient,

Passive resistance of the free supports. — These resistances are taken as 0.2 of the reaction in the case of sliding joints and as 0.03 in the case of joints with rollers.

Maximum stresses allowed. — The instructions divide the stresses into *main stresses* due to the dead weight, to the live load with impact, to centrifugal force, and to temperature changes. The total stresses are obtained by adding thereto the stresses due to *wind*, and the *supplementary stresses* due to braking, nosing, friction at the bearings, and to differences in level of the abutments and of the foundation piles.

The *main and total stresses* are limited in accordance with the quality of the metal used in the structure.

For ordinary mild constructional steel of an apparent elastic limit of 2 400 kgr. per square metre (15.2 English tons per square inch) the maximum allowable tensile stress is 1 400 kgr. per square centimetre (8.9 English tons per square inch) for the main stresses, and 1 600 kgr. per square centimetre (10.2 English tons per square inch) for the total stresses.

With *special steel* (Hochwertiger Baustahl), with an apparent limit of elasticity of 3 120 kgr. per square centimetre (19.8 English tons per square inch) the allowable stresses are 1 820 kgr. per square centimetre $= 1\ 400 \times \frac{3\ 120}{2\ 400}$ (11.6 English tons per square inch) for the main stresses and 2 080 kgr. per square centimetre (13.2 English tons per square inch) for the total.

The limits of stresses due to *slip* are 0.8 of those above.

Calculation of members in compression. Length of buckling. — In the booms the length of buckling is the theoretical length between the joints

For the diagonals, a distinction is made between buckling *outside* the plane of the girder and that *in* the plane thereof. In the first case, the length taken is the theoretical length between the joints : in the second, it is the distance between the presumed centres of gravity of the riveted attachments at the ends.

In the case of the struts in a main girder with bottom cross bearers and upper cross bracing, the length of buckling towards the outside of the girder is taken as between the upper and lower gusset plates.

Calculation of parts in compression through their axes. — The coefficient of yield λ is the ratio of the theoretical length of buckling S_K and the radius of gyration i :

$$\lambda = \frac{S_K}{i} \quad \text{and} \quad i = \sqrt{\frac{I}{F}},$$

where I = the moment of inertia, F = the section.

The calculation of the parts in compression is based on the following supposition :

1. Between the limits $\lambda = 0$ and $\lambda = 60$, the buckling load per square centimetre is taken as equal to the apparent elastic limit.

When $\lambda \gtrless 100$, Euler's formula is used to calculate it.

Between $\lambda = 60$ and $\lambda = 100$, the maximum loads are connected by a straight line representing the buckling loads between the extreme valves of λ.

2. The factor of safety ν in the zone to which Eulers's formula is applied when $\lambda \gtrless 100$ is taken as equal to *3.5*.

For $\lambda = 0$, it is supposed that the maximum working stress is the same either for bending or in tension, corresponding to a value of $\nu = 1.71$.

For intermediate values of λ between 0 and 100, ν is supposed to follow a law of parabolic variation of the second degree.

In the new German instructions as in those of 1923, tables are given by means of which the parts in compression can be calculated under the same working stresses as the parts in tension or bending. To provide against buckling, the total stress on the part is multiplied by a constant ω arrived at after considering the reduction necessary in the unit stresses allowable.

If σ_K represents the maximum unit buckling stress, $\frac{\sigma K}{\nu}$ is the maximum allowable stress, σ_D being the maximum stress allowed in tension or by bending,

$$\frac{\sigma_K}{\nu} = \frac{\sigma_D}{\omega}$$

If T is the total compression of the part and Ω is its cross section

$$\Omega = \frac{T}{\frac{\sigma_K}{\nu}} = \frac{T}{\frac{\sigma_D}{\omega}} = \omega \frac{T}{\sigma_D}$$

Ω can be calculated from the allowable bending σ_D, provided T is multiplied by ω.

The tables and diagrams in the regulations are given later on.

Calculation of parts in compression with lattice bracing. — If the part is made up of two U's in the form of a caisson with the tops joined together by lattice bracing or by plates, the centre line of the X, being the symmetrical axis of the U's and the centre line of the Y's, the axis in the open part, the moment of inertia along YY should be 10 % higher than that along XX.

In addition, the λ of the free parts (between attachment) should be at most equal to λ of the whole girder and in no case exceed 30.

The length of buckling of the free sections is measured between the inner rivets of the attachments (plate or lattice work).

The calculation of the stiffening lattice work should take into account a shear at least equal to 2 % of the compression stress in the whole girder without multiplying it by the constant ω.

The ends are securely held by strong assembly plates.

Open bridges. — When the booms in compression are not connected by wind bracing, it is necessary to check the stiffness of the transverse section, in order to provide against any buckling of the booms in compression.

The frame made up of the struts and the flooring should be checked by supposing a load perpendicular to the boom towards either the exterior or the interior equal in value to 1/100 of the greatest compression in the parts next to the boom, acting freely on the boom.

Riveting. — The maximum allowable shear is 8/10 of the tensile or bending stress.

The maximum allowable compression stress in the body of the rivet is 2.5 times the tensile or bending stress.

Stability against overturning. — In any doubtful case the stability should be checked with the floor either covered with vehicles or not. It is usual to suppose the floor to be covered with empty vehicles weighing 1.25 t. per lineal metre (1.12 English tons per yard).

Buckling stress σ_K and constants for buckling ω.

1	2	3	4	5	6	7	8	9	10	11	12
Iron and mild steel before 1895. Mean stress at the apparent yield point. $\sigma_S = 2\,200$ kgr./cm². Coefficient of elasticity: E = 2 000 000 kgr./cm².				Mild steel after 1894 and steel St 37. $\sigma_S = 2\,400$ kgr./cm². E = 2 100 000 kgr./cm².				High tensile steel St 48. $\sigma_S = 2\,400 + 0.3 \times 2\,400 = 3\,120$ kgr./cm². E = 2 100 000 kgr./cm².			
Coefficient of yielding $\lambda = \frac{s_K}{i}$	Buckling stress σ_K $\lambda \leqq 60$; $\sigma_K = 2\,200$ $\lambda \begin{matrix} \geqq \\ \leqq \end{matrix} \begin{matrix} 60 \\ 100 \end{matrix}$; $\sigma_K = 2\,539 - 5.65\,\lambda$ $\lambda \geqq 100$; $\sigma_K = \frac{19\,740\,000}{\lambda^2}$ kgr./cm²	Constant of buckling $\omega = \frac{\sigma_{zul}}{\sigma_{dzul}}$	$\frac{\Delta\,\omega}{\Delta\,\lambda}$	Coefficient of yielding $\lambda = \frac{s_K}{i}$	Buckling stress σ_K $\lambda \leqq 60$; $\sigma_K = 2\,400$ $\lambda \begin{matrix} \geqq \\ \leqq \end{matrix} \begin{matrix} 60 \\ 100 \end{matrix}$; $\sigma_K = 2\,890.5 - 8.175\,\lambda$ $\lambda \geqq 100$; $\sigma_K = \frac{20\,726\,000}{\lambda^2}$ kgr./cm²	Constant of buckling $\omega = \frac{\sigma_{zu'}}{\sigma_{dzul}}$	$\frac{\Delta\,\omega}{\Delta\,\lambda}$	Coefficient of yielding $\lambda = \frac{s_K}{i}$	Buckling stress σ_K $\lambda \leqq 60$; $\sigma_K = 3\,120$ $\lambda \begin{matrix} \geqq \\ \leqq \end{matrix} \begin{matrix} 60 \\ 100 \end{matrix}$; $\sigma_K = 4\,690.5 - 26.175\,\lambda$ $\lambda \geqq 100$; $\sigma_K = \frac{20\,726\,000}{\lambda^2}$ kgr./cm²	Constant of buckling $\omega = \frac{\sigma_{zul}}{\sigma_{dzul}}$	$\frac{\Delta\,\omega}{\Delta\,\lambda}$
0	2 200	1.00	0.001	0	2 400	1.00	0.001	0	3 120	1.00	0.001
10		1.01	0.001	10		1.01	0.001	10		1.01	0.002
20		1.02	0.004	20		1.02	0.003	20		1.03	0.003
30		1.06	0.005	30		1.05	0.005	30		1.06	0.006
40		1.11	0.007	40		1.10	0.007	40		1.12	0.008
50		1.18	0.009	50		1.17	0.009	50		1 20	0.012
60		1.27	0.014	60		1.26	0.013	60		1.32	0.017
70	2 143	1.41	0.021	70	2 318	1.39	0.020	70	2 858	1.49	0.027
80	2 087	1.62	0.032	80	2 237	1.59	0.029	80	2 597	1.76	0.045
90	2 030	1.94	0.054	90	2 155	1.88	0.048	90	2 335	2.21	0.086
100	1 974	2.48	0.052	100	2 073	2.36	0.050	100	2 073	3.07	0.065
110	1 632	3.00	0.057	110	1 713	2.86	0.055	110	1 713	3.72	0.071
120	1 371	3.57	0.062	120	1 439	3.41	0.059	120	1 439	4.43	0.077
130	1 168	4.19	0.067	130	1 226	4.00	0.064	130	1 226	5 20	0.083
140	1 007	4.86	0.072	140	1 057	4.64	0.068	140	1 057	6.03	0.089
150	877	5.58		150	921	5.32		150	921	6.92	

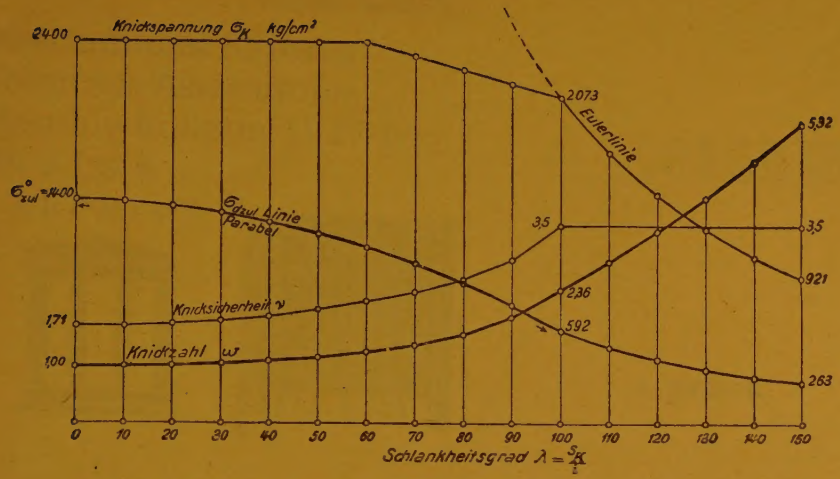


Fig. 1. — Curves of buckling stresses σ_K, of the allowable stresses in compression σ_{dzul}, of the factors of safety against bending, and of the constants ω for steel St 37 with a mean apparent elastic limit of 2 400 kgr. per cm² (15.2 English tons per square inch) (for new structures under the principal loads).

Explanation of German terms : Knickspannung = buckling stress. — Eulerlinie = Euler curve. — σ_{dzul} Linie = Curve of allowable stresses. — Knicksicherheit = Safety against buckling. — Knickzahl ω = Constant for bending ω. — Schlankheitsgrad = Coefficient of yielding.

The stability should not be less than 1.3 for moderate spans and 1.5 for long spans. If these co-efficients are smaller the bridge must be anchored properly.

Abutments. — The co-efficient of impact must be taken into account when calculating the abutments.

The new regulations contain valuable information on the resistance of the masonry work under the bearings.

When the bearings are laid on granite or dressed stone of other kinds, the stone should have a resistance to compression measured on cubes with 20 cm (7 7/8 inches) sides of at least 700 kgr. per square centimetre (4.4 English tons per square inch).

If the bearings are placed directly on concrete, the resistance of the concrete to compression should be not less than 300 kgr. per square centimetre (1.9 English tons per square inch) at the end of 28 days, measured in a test cube with 20 cm (7 7/8 inches) sides.

Maximum compression allowed on a joint made with cement mortar (1-1) or on the lead sheet under the metal : 50 kgr. per square centimetre (0.32 English ton per square inch)

Maximum compression allowed between the top masonry bearing blocks in granite or concrete, and the masonry below : 25 kgr. per square centimetre (0.16 English ton par square inch).

Maximum working load in bending or shear of the granite or dressed stone support : 15 kgr. per square centimetre (0.10 English ton per square inch).

The regulation contains many tables and charts to facilitate the calculation of railway bridges

R. Despretz.